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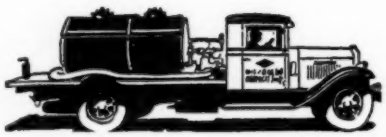

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Volume 21 Number 10

BULLETIN
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OCTOBER, 1937

STRATIGRAPHY VERSUS STRUCTURE IN ROCKY MOUNTAIN REGION[1]

ROSS L. HEATON[2]
Denver, Colorado

ABSTRACT

The existence of oil and gas accumulations in the Rocky Mountain region which are due to stratigraphic rather than structural traps, leads to an analysis of the conditions under which these accumulations occur and to a consideration of methods by which other similar deposits may be found. Examples of stratigraphic traps are not numerous in the Rocky Mountains but it is reasoned that such fields may have escaped discovery because wildcatting is almost invariably confined to favorable structure.

The problem is approached from the standpoint of source rocks as well as reservoir rocks. Localities in which there are apparent relationships between petroliferous provinces and ancient geography are described by reference to generalized paleogeographic maps of the Rocky Mountain region from Pennsylvanian to Cretaceous time. The nature of the sediments and the conditions under which they were deposited were profoundly affected by ancient positive elements which are called the "Ancestral Rockies."

Numerous instances of lenticular and wedging sand bodies are pointed out as having possibilities for the formation of stratigraphic traps on the flanks of major uplifts or in structural basins. A great deal of detailed stratigraphic work must supplement the present general knowledge.

INTRODUCTION

In the Rocky Mountain region there are several oil and gas fields which owe their existence to factors other than anticlinal structure. Only two or three of them are of particular importance from the standpoint of total recovery but they are significant in that they suggest the possibility of finding other fields of equal or greater importance. The proportion of past production from fields of the stratigraphic type, as defined by Levorsen,[3] is much more impressive in other

[1] Read before the Association at Los Angeles, March 17, 1937. Manuscript received, July 2, 1937.

[2] Geologist, 2374 Elm Street.

[3] A. I. Levorsen, "Stratigraphic Versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 5 (May, 1936), p. 524.

regions than in the Rockies. He presents figures to show that

> of the 22 largest oil pools in the United States, more than half of the oil production was obtained from pools in which the dominant trap-making element was a change from porosity to non-porosity.

In view of these facts and recognizing the necessity of maintaining an annual supply of more than 1 billion barrels of oil, it seems strange that more systematic and concerted efforts have not been directed toward the development of a technique which might lead to the discovery of pools other than those due to anticlinal structure. Geophysics has played an important part in maintaining the supply of oil in the last few years. Geophysical methods, however, are simply other ways of finding structure and the supply of favorable structures will eventually be exhausted.

In the Rocky Mountain area most of the oil and gas fields are on closed anticlines. Practically all of the apparent structures have been drilled. There are many localities in which indications of favorable structure exist, partly covered by late formations, and many of these have also been drilled. Not only have most of the favorable localities been tested but very little prospecting has been done "off structure." It therefore seems reasonable to suppose that, if there are oil pools present of the stratigraphic type, they would probably have escaped discovery more readily than in the Mid-Continent or Eastern areas; and a study of geologic history reveals that in several periods there existed relationships between high areas and basins of deposition in the Rocky Mountain region, such as to indicate very favorable possibilities for oil accumulation in wedging or truncated sands in the presence of source beds.

The possible relationships of geologic history and productive areas have been recognized for many years and the more or less direct application of the principles involved were discussed by Schuchert[4] and Woodruff[5] in 1919, by McCoy[6] in 1921, White[7] in 1922, and Ver Wiebe[8] in 1929. The first comprehensive discussion of the application

[4] Charles Schuchert, "Relations of Stratigraphy and Paleogeography to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 3 (1919), p. 286.

[5] E. G. Woodruff, "Petroliferous Provinces," *Amer. Inst. Min. and Met. Eng. Bull. 150* (June, 1919), pp. 907–12.

[6] Alex W. McCoy, "A Short Sketch of the Paleogeography of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September–October, 1921), p. 541.

[7] David White, "Problems in Oil Geology and Their Advancement through Cooperative Research," *ibid.*, Vol. 6, No. 6 (November–December, 1922), pp. 509–15.

[8] Walter A. Ver Wiebe, "Tectonic Classification of Oil Fields in the United States," *ibid.*, Vol. 13, No. 5 (May, 1929), pp. 409–40.

of paleogeology was by Levorsen[9] in 1933. In 1936[10] he pointed out many significant facts with respect to production in stratigraphic traps and directed the attention of petroleum geologists to methods and possible results of intensive studies along this line and the need for such studies. The writer[11] expressed some ideas on the subject in 1933.

METHODS

Source beds, sand lenses, wedging sands, and unconformities all are related to shore lines. The position and direction of ancient shore lines are governed by ancient geography. Hence, the importance of paleogeographic maps.

Beneath unconformities are truncated sandstones and limestones, eroded structures and weathered surfaces. Over them are perhaps shale deposits or wedging sands due to progressive shore lines. It is important to know the stratigraphic position of these unconformities and the amount of geologic time represented.

A study of sedimentation is essential. We must know the sources of the sediments and, by a study of sedimentary petrology and geologic history, learn something of the climatic conditions and general environment under which the strata were deposited.

The searcher for oil pools of the stratigraphic type must keep himself informed concerning everything that has been done with respect to research on the origin of oil, the nature and manner of occurrence of source beds, studies of modern sediments, causes and processes of change from the original organic material to petroleum, movement from source beds to reservoir rocks, and, finally, migration and accumulation. The search for stratigraphic pools involves a different approach to problems of petroleum geology from any that has prevailed in the past and may, in itself, furnish valuable additions to the accumulated data on various controversial theories regarding the foregoing subjects.

Such a study should not only give clues as to the location of promising areas from the standpoint of source beds, but also should indicate the areas in which reservoir sands are present, where they pinch out, where they are truncated, *et cetera*.

[9] A. I. Levorsen, "Studies in Paleogeology," *ibid.*, Vol. 17, No. 9 (September, 1933), p. 1107.

[10] ———, "Stratigraphic Versus Structural Accumulation," *ibid.*, Vol. 20, No. 5 (May, 1936), p. 521.

[11] Ross L. Heaton, "Some Problems in the Search for Future Oil Fields," talk before Colorado Engineering Council, May 16, 1933. Abstract in *Inland Oil Index* (May, 19, 1933).

The first steps involve general correlations and the construction of general maps such as has been attempted in this paper. A more detailed study must follow as material becomes available. Many paleogeographic maps must be made where now there is only one; also paleogeologic maps which show the areal geology at various periods and which will contribute to the structural history; also cross sections, isopach maps, *et cetera*.

All this will require a great deal of work. It will mean the measuring and sampling of sections and general stratigraphic study in the field. It will mean careful well sampling and examination of the samples and probably the drilling of wells for samples only. The lines of research involved appear to be without number. Men will be required who are especially trained in the stratigraphy of the area in which they are working, in paleontology, petrology, physics, geophysics, and kindred subjects.

The Rocky Mountain region is ideal for stratigraphic studies. Great thicknesses of sedimentary rocks for measuring and sampling are exposed within wide areas. Many well data are available between the main exposed regions, such as mountain uplifts. Generalized data on ancient land areas and shore lines already exist. Aside from the economic value, this work will furnish a great and valuable contribution to stratigraphic and historical geology.

FIELDS OF STRATIGRAPHIC TYPE IN ROCKY MOUNTAIN REGION

Cut Bank field.—The Cut Bank field is in Glacier County, northern Montana. It was discovered in 1932 and had produced 7 million barrels of oil to the end of 1936.

The Cut Bank field is on the west flank of the Kevin-Sunburst dome, which comprises the northern part of the Sweetgrass arch, a major area of uplift 120 miles long and 70 miles wide. The reservoir sand is the basal member of the Kootenai formation of Lower Cretaceous age and is underlain by the marine shales and limestones of the Jurassic Ellis formation. The sand wedges out updip over the older formations, forming a stratigraphic trap. The next higher sand of the Kootenai, the Sunburst, continues eastward over the uplift.

Kevin-Sunburst field.—The Kevin-Sunburst field is in Toole County, northern Montana. It was discovered in 1922 and at the end of 1936, had produced 31,500,000 barrels of oil.

The Kevin-Sunburst dome has a closure of 850 feet and an area of nearly 800 square miles. The producing area is on the northwest flank of the dome and is 200–250 feet, structurally, below the top. The main producing horizon is at the unconformable contact between the

Jurassic Ellis formation and the Madison limestone of Lower Mississippian age. The producing "sand" consists of the erratic porous layer at the base of the Ellis and the equally erratic areas of porous or cavernous limestone in the top of the Madison. The latter are unquestionably due to pre-Jurassic weathering. According to Howell[12]

> There is no oil production on top of the structure, but a study of the map indicates that local structure in areas of porosity has a decided effect on accumulation.

He states further that

> The factors other than structure which have affected accumulation are amount of porosity and nature of the contact zone, as well as the unconformity itself and a variable condition of water saturation.

Osage field.—The Osage field is in Weston County, northeastern Wyoming. It was discovered in 1920 and had produced 3,500,000 barrels of oil at the end of 1936.

The structure at the Osage field consists of two southwestward dipping terraces separated by a zone of steeper southwest dips.[13] The production occurs on both sides of and in the zone of steeper dips. It comes from the Newcastle sand, of Upper Cretaceous age, near its eastern limits. Its wedging-out is accompanied by lensing or a variation in porosity due to changes from sandstone to sandy shale. Accumulation is due mostly to this feature, although the flattening of the beds on the structural terraces may have been a contributing factor. The Black Hills uplift is on the northeast and the Powder River structural basin on the southwest.

SHALE OIL

Of the 33,500,000 barrels of oil thus far produced in Colorado, nearly half has been from shale. Obviously the prediction of shale production can not be approached from the standpoint of reservoir rocks, but, since shale oil is undoubtedly indigenous to the producing rock, the problem is one of source beds. It is possible that at some future date geologists may bring their knowledge of the origin of oil, environment of source beds, stratigraphic details, and paleogeography to the point of specific prediction as to localities of source beds. We scarcely know how to begin such a study at present and must necessarily deal in generalities. However, shale oil remains as a source of part of our future oil supply and should not be ignored.

[12] W. F. Howell, "Kevin-Sunburst Oil Field, Toole County, Montana," *Structure of Typical American Oil Fields*, Vol. 2 (Amer. Assoc. Petrol. Geol., 1929), p. 263.

[13] A. J. Collier, "The Osage Field, Weston County, Wyoming," *U. S. Geol. Survey Bull. 736-D* (1923), p. 88.

Structural studies are necessary also because shale oil seems to occur only where flexing has caused cracks and crevices to form in impervious rocks.

Florence-Canon City field.—The Florence-Canon City field, in southern Colorado, was discovered in 1862, one of the first in the United States. At the end of 1936 it had produced more than 13 million barrels of oil. Production is from fissures in the Pierre shale of Upper Cretaceous age. Of the structure, DeFord says[14]

> The field is on the east flank of a somewhat complicated synclinal basin that lies between two major anticlinal folds, the Wet Mountains on the west and the southward prolongation of the axis of the Front Range on the east.

Rangely and Tow Creek fields.—The Rangely and Tow Creek fields were discovered in 1919 and 1924, respectively. At the end of 1936 Rangely had produced 432,000 barrels and Tow Creek, nearly 1,500,000 barrels.

These fields produce from the Mancos shale at horizons equivalent to a part of the Pierre shale of eastern Colorado. In the Rangely dome the production is at the change from gentle to steep southwest dips. On Tow Creek anticline the production is near the anticlinal axis. The best wells are located on that part of the structure where the steep east dip begins.

RELATIONS OF PRODUCTIVE AREAS TO PALEOGEOGRAPHY

A study of some of the paleogeographic maps on which are shown the oil and gas fields which presumably either produce or have their source beds, or both, in the formation of the period represented, indicates an apparent relationship between the physiographic features and the productive areas. In a broad way the relationships seem to have a more direct connection with the occurrence of source beds than with reservoir rocks. Perhaps more local relationships might be brought out by more specific maps involving less thickness of beds and a shorter time interval.

The extent to which paleogeography has influenced the localities of oil occurrence will be in dispute, depending on the interpretations of different geologists. These interpretations will depend on the theories accepted by this or that geologist with respect to questions such as migration, flushing, effect of faulting, *et cetera*. There may be good structures without production in the vicinity of producing fields with the same formations involved. An example is the Shiprock district of

[14] Ronald K. DeFord, "Surface Structure, Florence Oil Field, Fremont County, Colorado," *Structure of Typical American Oil Fields*, Vol. 2 (Amer. Assoc. Petrol. Geol., 1929), p. 82.

San Juan basin, New Mexico. One geologist may explain this by flushing or by the relation of the structural elevation of the producing sand to the movement of water in the sand in the basin as a whole. Another geologist may see no explanation other than a lack of source beds.

The theory of a local source is championed by some geologists while others argue for long-distance migration. If the former theory is correct, the locality of source beds is of outstanding importance; if the latter, then full attention should be directed to traps for oil accumulation.

In the development of a technique for determining the localities of possible production irrespective of anticlinal structure, the investigator must familiarize himself with all of the evidence for and against the various theories of oil genesis, migration, and accumulation, and decide, at least tentatively, which of them appears to be the most applicable to the problems which confront him in his particular locality. He must maintain an open-minded attitude and be on the alert for new evidence.

The maps submitted with this paper were, with two or three exceptions, published in 1933.[15] Only those which have a bearing on oil or gas occurrence are reproduced here and some of these have been changed due to the acquisition of new data. Not only oil fields but prominent showings and occurrences of oil shale are shown.

EARLY PENNSYLVANIAN

Figure 1 shows in a general way the relationships of land and water from the beginning of Pennsylvanian deposition in the Rocky Mountain region until the end of Kansas City time. Areas of salt and gypsum have been added to the original map.

All fields of Wyoming produce from the Tensleep sandstone, which was deposited in the later stages of the period represented by Figure 1 and extended into later Pennsylvanian (Fig. 2). The same fields are shown on both maps and are discussed later.

The upper part of the Minnelusa formation of the Black Hills is mostly sandstone and corresponds with the Tensleep. The lower part contains black shales and limestones as well as sandy beds. One section near Hot Springs, South Dakota, contains oil shale. There have been good showings of oil in this part of the Minnelusa in at least three wells in the southwestern part of the Black Hills, located on

[15] Ross L. Heaton, "Ancestral Rockies and Mesozoic and Late Paleozoic Stratigraphy of Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 2 (February, 1933), pp. 109–68.

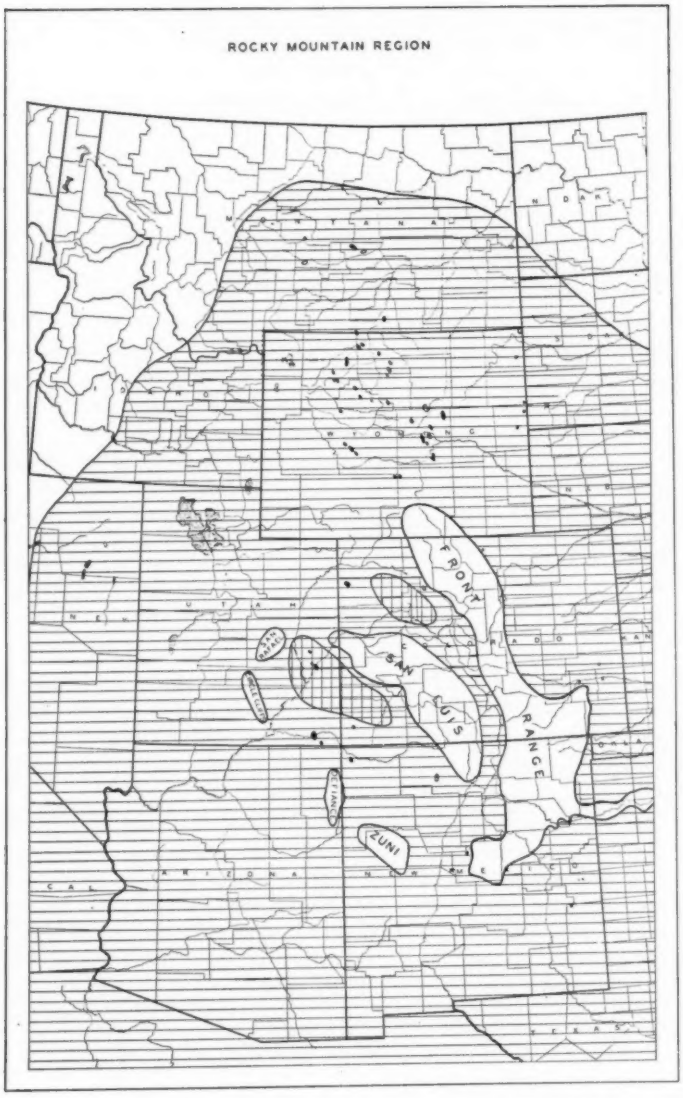

FIG. 1.—Paleogeography of Lower Pennsylvanian. Oil and gas fields in solid black. Outstanding structures proved dry are outlined in black. Ruled areas are marine depositional basins. Crossed lines show areas of salt and gypsum. Crosses indicate oil-shale localities.

Mule Creek and Old Woman Creek anticlines and near Edgemont, South Dakota. The latter was reported as a 5-barrel showing.[16]

Farther north, at Rocky Ford, 10 miles northeast of Sundance, Wyoming, the top member of the Minnelusa is saturated with oil on the outcrop. It corresponds with the Tensleep of other localities. An eroded anticline is present but the saturation is absent on the high parts of the structure and occurs mostly below the lowest closing contour on the southwest side only. It occurs on both sides of the syncline and there is a small oil field on the synclinal axis.

The saturated sands are closely associated with bedded gypsum. There are alternations of gypsum and sandstone and even lenses of saturated sandstone in the gypsum. Moreover, the occurrence of the saturated rock and the gypsum is co-extensive and the structure has apparently had no influence on the occurrence of the oil. The maximum thickness of the gypsum and saturated sands is 90 feet.

It might be argued that this is residual oil which escaped from the structure downdip after erosion had progressed sufficiently to release the hydraulic pressure which originally had retained the oil in the anticline. The escape would begin where erosion first uncovered the sand. In the case of the Rocky Ford anticline this would have been in the canyon of Sand Creek at the east end of the structure, where all of the Minnelusa and part of the Pahasapa (Mississippian) are now exposed. Neither oil saturation nor gypsum is present in the top of the Minnelusa at this point.

The logical conclusion is that the oil is indigenous to the containing sandstone and that the conditions under which the gypsum was deposited were favorable for the formation of source material. The shore line of the Pennsylvanian sea was comparatively close on the northeast. It is suggested that a detailed stratigraphic study may indicate the locality and extent of this or other semi-inclosed basins which might have oil possibilities.

The conditions under which the oil occurs suggest the application of the humic-acid theory of origin as set forth by Haseman[17] and Rae.[18] This theory may also apply to occurrences such as the Athabaska tar sands and the asphalt sands of the Wasatch formation in the Uinta basin, Utah.

In a part of southeastern Colorado, Pennsylvanian sediments are

[16] W. W. Rubey, "Possibility of Finding Oil in Anticline near Edgemont, South Dakota," *U. S. Dept. Interior Memorandum for Press* (August 19, 1926).

[17] J. D. Haseman, "Origin and Environment of Source Sediments of Petroleum Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930), pp. 1465–68.

[18] Colin C. Rae, "Organic Material of Carbonaceous Shales," *ibid.*, Vol. 6, No. 4 (July–August, 1922), pp. 333–41.

absent from the Las Animas arch, a northeast projection of that part of the "Front Range" land area. The arch continues as a buried granite ridge at least as far as the center of the east boundary of the state. The Lower Pennsylvanian has yielded important showings of oil in several wells on, and adjacent to, this buried ridge. Farther south, on the east side of the ancient highland, there is evidence that approximately 4,000 feet of beds ranging from Ordovician to Permian age have played out within a few miles from the basin toward the buried ridge.[19] The question of unconformities on the ridge and of unconformities, truncation, overlap, or depositional wedging against the ridge would seem to give ample opportunity for stratigraphers to decipher details of geologic history with profitable results.

Southeastern Utah, southwestern Colorado, and northeastern New Mexico comprise a depositional basin in which there are several occurrences of oil in Pennsylvanian beds. There is Pennsylvanian production in the Rattlesnake field of northwestern New Mexico and the San Juan field of southeastern Utah in the lower Hermosa or Goodridge formation. Considerable oil was found in the Moab district, eastern Utah, in the Paradox formation which lies below the Hermosa.[20] Good showings of oil and gas in the McElmo dome in southwestern Colorado came from higher in the Pennsylvanian. Shale yielding 30 gallons of oil per ton was found in the Magdalena formation in Sandia Mountains, east of Albuquerque, New Mexico.

The occurrence of oil, especially in the lower part of the Pennsylvanian, seems to bear a definite relationship to the margin of the basin but whether the formation of source beds is controlled by such a broad feature is yet to be learned. It is probable that favorable conditions were present only locally but that the position of these local areas bears a definite relationship to the shore lines.

The Paradox formation, in which the oil was found at Moab, is mostly gypsum and salt, with associated black shales and limestones. Deposition was apparently in a basin which was cut off from the sea except for an inlet to supply water for evaporation.[21] The approximate extent of the saliferous deposits is shown on Figure 1; also shown is a smaller basin of similar nature in northwestern Colorado, where gypsum occurs in beds considerably younger than the Paradox formation. The oil which was found in the Rangely dome was from

[19] Ross L. Heaton, *op. cit.*, p. 136.

[20] A. A. Baker, "Geology and Oil Possibilities of the Moab District, Grand and San Juan Counties, Utah," *U. S. Geol. Survey Bull. 841* (1933), p. 81.

[21] A. A. Baker, C. H. Dane, and John B. Reeside, Jr., "Paradox Formation of Eastern Utah and Western Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 8 (August, 1933), p. 979.

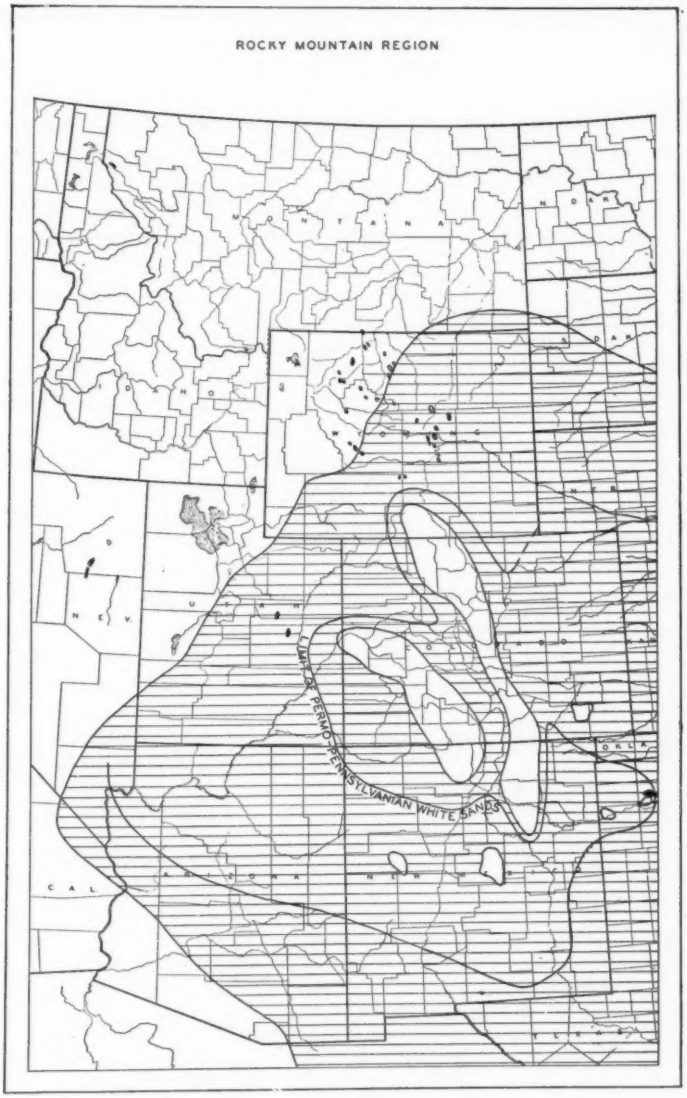

FIG. 2.—Paleogeography of late Pennsylvanian and Permo-Pennsylvanian. Oil and gas fields in solid black. Outstanding structures proved dry are outlined in black. Ruled areas are marine depositional basins.

the Weber sandstone and is comparable with the Tensleep production of Wyoming.

In the Holbrook area of eastern Arizona southwest of the "Zuni" and "Defiance" elements there was another area of black shale and limestone deposition accompanied by salt in the later stages. Another semi-inclosed basin is indicated here and its existence is corroborated by evidence of a high Pennsylvanian area in the Grand Canyon district. The Permian Supai formation rests on the Redwall limestone of Mississippian age.[22] A land area which appeared in southwestern Arizona in late Pennsylvanian or early Permian time (Fig. 2) may have attained sufficient prominence in earlier Pennsylvanian time to have completed the inclosure of this basin.

LATE PENNSYLVANIAN AND PERMO-PENNSYLVANIAN

Figure 2 represents a composite of late Pennsylvanian and early Permian time.

All the oil and gas fields in Wyoming produce from the Tensleep sandstone and are the same as those shown in Figure 1. In northwestern Wyoming the shore line had shifted to the southeast, exposing to erosion a great area of the Tensleep of the older Pennsylvanian. Sands from this territory continued to furnish material for deposition in the more restricted basin on the southeast and there was undoubtedly a zone of considerable width in the region of the shore line as shown in Figure 2, in which oscillatory conditions resulted in the presence, in the same section, of sandstones resulting from both the earlier and later periods of deposition. Areas on both sides of the shore line, as shown by Figure 2, were later covered by the marine beds of the Embar formation (Fig. 3) and these evidently contained source beds.

It is generally agreed that the Embar supplied the source material for all of the Tensleep fields of Wyoming.[23] An examination of the Embar map (Fig. 3) throws some doubt on this assumption, however. There seems to have been no other possible source than the Embar for the Tensleep oil in the western group of fields because the Tensleep lies directly on the Amsden formation and is itself entirely sandstone. For the eastern group of fields the stratigraphic picture has changed, both above and below the Tensleep. The Embar has changed

[22] A. A. Baker, "Geology and Oil Possibilities of the Moab District, Grand and San Juan Counties, Utah," *U. S. Geol. Survey Bull. 841* (1933), pp. 17–19.

[23] John G. Bartram, "Oil Gravities in the Rocky Mountain States," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 161.
H. F. Davies, "Structural History and Its Relation to the Accumulation of Oil and Gas in the Rocky Mountain District," *ibid.*, p. 687.

from typical marine sediments to red beds, gypsum, and thin limestones. The line separating the true marine basin and the area of red-beds deposition is farther west than that shown by Bartram[24] and leaves the eastern group of Tensleep fields outside the marine Embar basin. This seems to eliminate the Embar as the source of the oil in those fields and leads to a consideration of other possible sources.

Stratigraphic data are at hand which indicate another stage in the geologic history of central Wyoming, but they are scarcely adequate for the construction of another map. Such a map might be labeled "Late Lower Pennsylvanian" and would belong between Figures 1 and 2 of this paper. It would show an extension of the "Front Range" positive element slightly west of north across central Wyoming, including practically all of Bighorn Basin. In this area the Tensleep consists wholly of sandstone and lies unconformably on the Amsden formation or on the Madison. It varies greatly in thickness due in part at least to the uneven surface upon which it was deposited. On each side of this positive element the sandstone of the Tensleep is, in its lower part, interbedded with fossiliferous limestones and shales and underlain by older beds of similar nature, the latter being younger than the Amsden formation. Such beds are the lower part of the Wells formation of Idaho, the Casper formation east of the town of Casper, and the Minnelusa of the Black Hills. In northern Wyoming, on the eastern side of the Bighorn Mountains, the boundary of this ancient positive element is determined roughly by measured sections on Amsden Creek, northern Sheridan County, and on the north fork of Crazy Woman Creek in Johnson County. In the former, 100 feet of sandstone lie directly on the Amsden formation. In the latter, there are 380 feet of sandstone, with limestone in the lower part, underlain by 150 feet more of limestones and shales above the typical Amsden beds.

The eastern boundary of this pre-Tensleep high area happens to coincide roughly with the line of change from non-red to red sediments on the Embar map. Off the eastern edge of the positive area several sections, such as at Ervay in the Rattlesnake Mountains, at Alcova and at No Wood in the Bighorn Basin, begin to show limestones and shales, especially in the lower part. These increase in thickness downward and east and form the greater part of the Casper formation eastward toward Douglas. They correspond in a general way with the lower Hartville of the Hartville uplift and probably with a part of the Minnelusa of the Black Hills. Since the Embar marine beds do not extend east of this positive element, the most

[24] John G. Bartram, *op. cit.* Figs. 2 and 3, pp. 162, 164.

logical source of the oil in the Tensleep sand of the eastern group of fields appears to be in these lower beds. A recent discovery in the Tensleep at Lance Creek bears out this assumption. The Embar is not productive in this area.

The gas in the Farnham and Woodside anticlines in Utah is in the Coconino sandstone, but the source material is doubtless in the overlying Kaibab limestone (Fig. 3).

In the later stages of their deposition the Tensleep and related formations wedged out toward the Ancestral Rockies and as a rule interfingered with the red beds which were derived from the Front Range and San Luis positive elements. In northern Colorado the Ingleside formation merges southward into the Fountain formation. In northwestern Colorado the Weber disappears between the Utah state line, where it is 1,000 feet thick, and the Flat Top uplift, except for the extreme upper part which is 90 feet thick at the latter locality. The thinning continues to Glenwood Springs and the formation wedges out a short distance farther southeast. On White River and at Glenwood Springs it lies on the red beds of the Maroon formation, which is absent at the Utah line and also at Cross and Juniper Mountains, a considerable distance into Colorado. In southeastern Utah the Coconino merges into the upper Cutler formation of the San Juan Mountains.[25]

The edge of this great sandstone wedge presents opportunities for more detailed work in determining localities where it wedges out updip and is associated with source beds. Such localities may be found in the eastern part of Red Desert basin in southwestern Wyoming, southeastern Uinta basin in northwestern Colorado, or the San Juan and Raton basins of New Mexico.

PERMO-PENNSYLVANIAN AND PERMIAN

Figure 3 shows the extent of marine non-red and red-beds deposition which, in the west, began before the end of Pennsylvanian time. The lower Park City and Embar formations are late Pennsylvanian. Unquestionably this invasion of marine waters from the Pacific began before the deposition of the light-colored sands had reached its maximum extent, the later stages of sand distribution being mostly by wind action. Thus Figure 3 overlaps Figure 2 in point of time. In the region exposed to erosion by the southeastward recession of the shore line (Fig. 2) there is an unconformable contact between the Embar and Tensleep of Wyoming and between the Park City and

[25] A. A. Baker and John B. Reeside, Jr., "Correlation of the Permian of Southern Utah, Northern Arizona, Northwestern New Mexico, and Southwestern Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 11 (November, 1929), p. 1443.

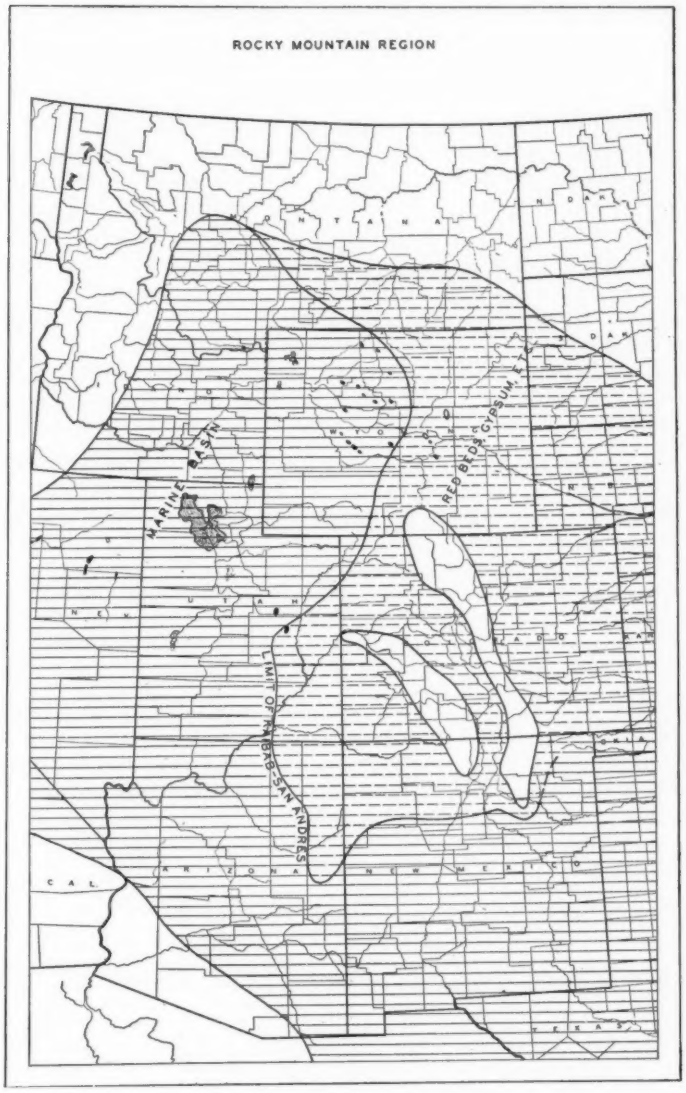

FIG. 3.—Paleogeography of Permo-Pennsylvanian and Permian. Oil and gas fields in solid black. Outstanding structures, proved dry, are outlined in black.

Weber of Utah. Farther south there is a gradational contact between the Kaibab limestone and the Coconino sandstone. The Kaibab, near its eastern limit, probably represents only the upper Kaibab of the area on the north and west. The Coconino of the eastern area is therefore equivalent in age to a part of the Kaibab farther west.[26]

As shown by the map (Fig. 3), the producing fields of the Embar are confined to the marine basin with the exception of Bolton Creek. It is possible that the oil in both the Embar and Sundance formations in this field is not indigenous to those formations, since both yield black oil. The Sundance usually produces light oil. In all other fields it is assumed that the Embar contains its own source beds.

The Salt Creek field is an outstanding example of a good structure which is productive in the Tensleep but not in the Embar.

The two gas fields in Utah are from the Coconino sandstone, which is here overlain by the Kaibab limestone. The Farnham anticline is northwest of the Woodside structure and the gas is nearly pure carbon dioxide with small amounts of oxygen and hydrogen sulphide. The Woodside gas is 31.7 per cent carbon dioxide, 62.3 per cent nitrogen, 5.7 per cent ethane, and 1.31 per cent helium with small amounts of oxygen.

Dobbin[27] cites several theories as to the probable origin of the carbon dioxide in natural gases. It may be the result of incipient metamorphism in basement rocks lying at shallow depths, by oxidation of the hydrocarbons through contact with mineralized waters, or by the metamorphic action of hot magmas intruding limestone. Hammar[28] and McCoy[29] have shown that the end products of aërobic bacterial action may be carbon dioxide and water. Inasmuch as there are ordinarily small amounts of methane and ethane in gases rich in carbon dioxide, this explanation may be found more applicable than the other theories mentioned to the conditions under which carbon dioxide is found in some of the Rocky Mountain fields. That being the case, we revert again to the question of source beds. The Farnham and Woodside fields are very near the eastern limits of the Kaibab limestone in Utah and there may be a relationship to the eastern

[26] James Gilluly and John B. Reeside, Jr., "Sedimentary Rocks of the San Rafael Swell and Some Adjacent Areas in Eastern Utah," *U. S. Geol. Survey Prof. Paper 150-D* (1928), p. 63.

[27] C. E. Dobbin, "Geology of Natural Gases Rich in Helium, Nitrogen, Carbon Dioxide, and Hydrogen Sulphide," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), pp. 1067–69.

[28] Harald E. Hammar, "Relation of Micro-Organisms to Generation of Petroleum," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 36.

[29] Alex W. McCoy and W. Ross Keyte, "Present Interpretations of the Structural Theory for Oil and Gas Migration and Accumulation," *ibid.*, pp. 262 and 268.

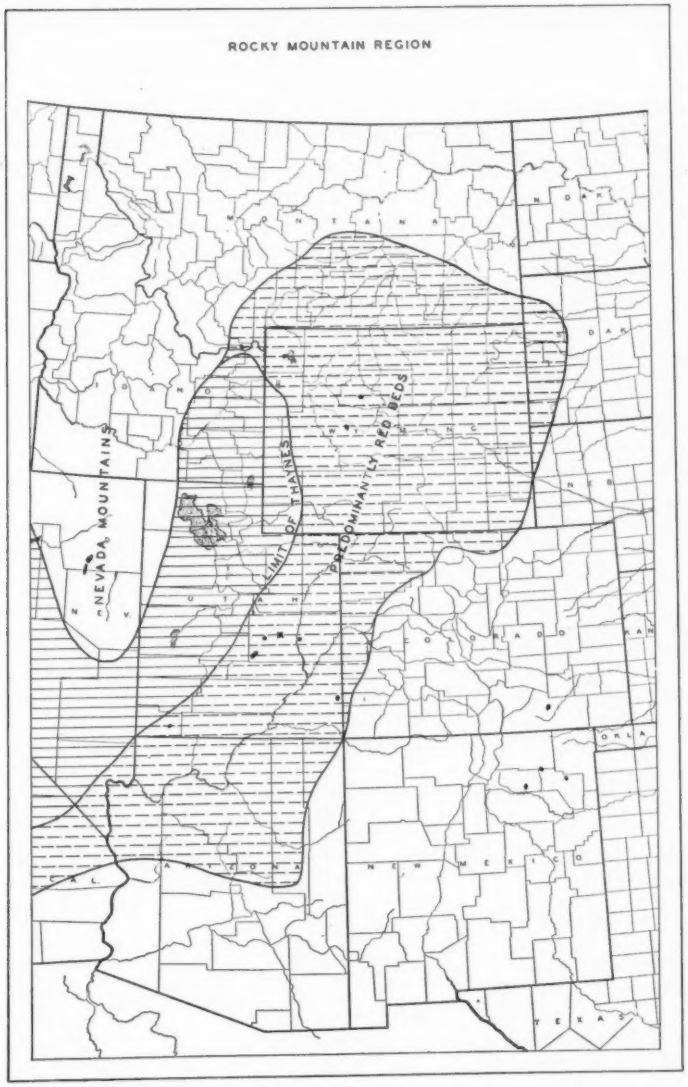

FIG. 4.—Paleogeography of Lower Triassic. Oil and gas fields or notable showings in solid black, some of which are from Upper Triassic. Surface saturation shown by cross.

limit of the marine basin similar to that of the Embar fields of Wyoming.

The Woodside gas, besides its carbon-dioxide content, is high in nitrogen and contains some helium. According to Rogers,[30] most gases having appreciable percentages of helium are of the nitrogen type and he suggests that the origin of the two may be in some way related. After reviewing the various theories of origin, the same author[31] gives as his preference the theory of derivation from radioactive elements. This theory seems to be strengthened by the occurrence of helium in many localities in reservoirs relatively close to basement rocks, as pointed out by Dobbin.[32] If this should develop into a tenable theory, the locality of ancient positive elements may present clues as to the location of additional supplies of helium and, conversely, the discovery of helium may be considered as indicative of the presence of positive elements, the existence of which had not been determined by stratigraphic studies.

LOWER TRIASSIC

Figure 4 shows the area submerged more or less continuously during Lower Triassic time. The Nevada Mountains are shown as extending farther south than in the original map and an attempt has been made here to show the limits of the true marine basin in which the Thaynes limestone and equivalents were deposited. Thin limestones, such as the Virgin series of southwestern Utah and the Sinbad of the San Rafael country, extended farther east, but that section as a whole is predominantly made up of red beds.

Along the western border of the red-beds area there is an alternation of gray and red sandstones and sandy shales, especially in the lower part of the Moenkopi formation. These show oil saturation at several horizons on San Rafael River at the mouth of Buckhorn Draw. On Green River there are seepages and small wells in the Moenkopi, and at Salt Wash wax and some oil were found in the same horizon. A good flow of gas was found in the Moenkopi on Last Chance anticline and the old Virgin field in southwestern Utah gets its oil from the basal member. The Virgin limestone member furnishes seepages.

It may be significant that all the foregoing occurrences are near the zone of change from the Thaynes basin to the area of alternating

[30] G. Sherburne Rogers, "Helium-Bearing Natural Gas," *U. S. Geol. Survey Prof. Paper 121* (1921), p. 38.

[31] *Op. cit.*, p. 68.

[32] C. E. Dobbin, *op. cit.*, p. 1064.

gray and red sediments. This zone also marks the decrease in porosity from the sandy beds of the east to the impervious limestones and shales of the west. The shales accompanying the thick limestones of the Thaynes are olive and pink instead of black or gray, the colors usually associated with source beds.

The two fields of Wyoming have some production in the red beds of the Chugwater formation but the source is probably in the Embar.

The Boulder Knoll field in southeastern Utah produces gas from the Shinarump conglomerate of Upper Triassic age. The fields of New Mexico and Colorado are also in the Upper Triassic but no map for that period is included in this paper because of the unimportance of the fields and the fact that the occurrence of the gas was probably not influenced by Upper Triassic paleogeographic features. The relationship seems rather to have been with older geologic history, since all of these fields are in the area of the Front Range positive element of Pennsylvanian time and the producing sands are not far removed from the basement rocks. They produce non-inflammable gas, mostly carbon dioxide. The gas from the Abbott anticline, in Colfax County, New Mexico, contains 28 per cent nitrogen. Gas from the Model dome in southeastern Colorado contains 80 per cent nitrogen and 7 per cent helium. None of the analyses of gas from these fields shows ethane or methane. There are no beds associated with the producing sandstone (Santa Rosa) that have the appearance of containing source beds for petroleum. These facts give support to the theory that gases of the nitrogen type were derived from radioactive elements.

JURASSIC

Figure 5 shows the distribution of the Entrada or Sundance sandstone and the area of marine deposition which immediately followed it. The Entrada and its equivalents are probably almost entirely of eolian origin. The upper part was reworked by marine waters advancing from the north. In this marine basin were deposited a part of the Ellis formation of Montana, the Sundance of Wyoming, and the Curtis of Utah and western Colorado. The boundary of the marine basin in Colorado and Utah is changed from the original map to conform to new data published by Baker, Dane, and Reeside.[33] The same publication was the basis for slight changes in the south boundary of the Entrada in Utah and northwestern New Mexico. The remainder of the Entrada map differs widely from that of Baker, Dane, and

[33] A. A. Baker, C. H. Dane, and John B. Reeside, Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936), p. 50.

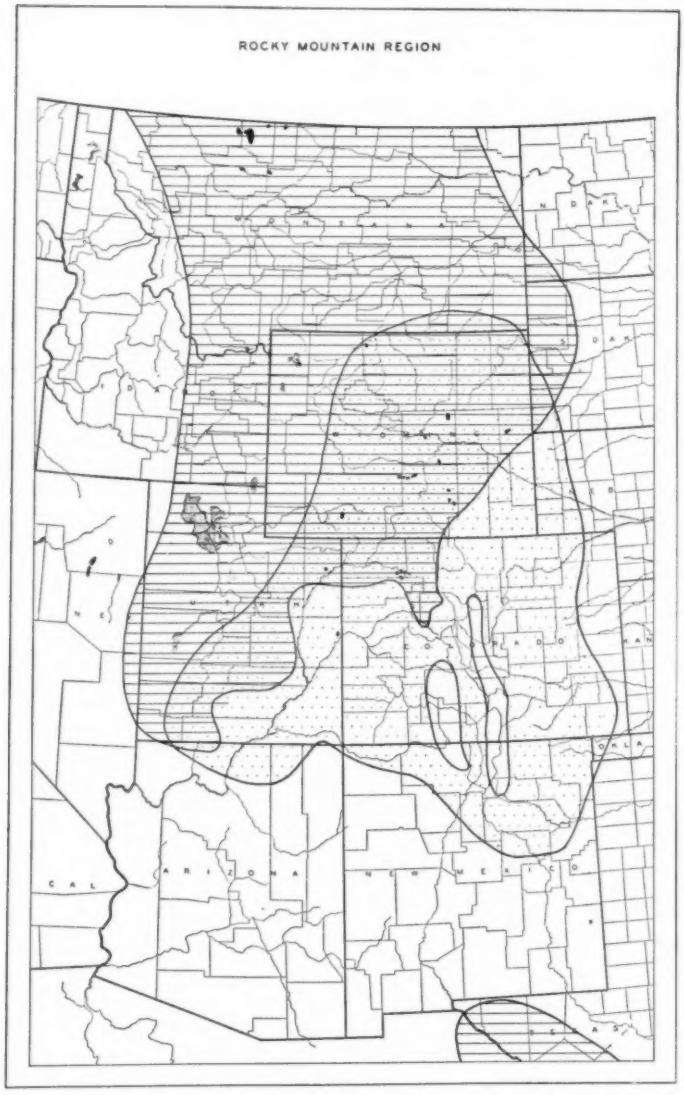

FIG. 5.—Paleogeography of part of Upper Jurassic. Ruled area is basin of marine deposition. Dotted area indicates predominant eolian sediments. Producing fields in solid black.

Reeside, for reasons given in the original paper.[34] More data on conditions east of the Colorado Front Range might show a patchy distribution of the Entrada from the neighborhood of Boulder southward to a point east of Canon City. The zone might extend a considerable distance eastward. Foothills exposures in this zone show several sections in which the sandstone is absent. From Morrison southward, sections showing the sandstone alternate with those showing gypsum at the same stratigraphic position, but in no section do both occur. The gypsum is considered as the equivalent of the Todilto formation of New Mexico. In the latter locality the gypsum occurs above the sandstone. The same relations exist between the Exter sandstone and the overlying gypsum in southeastern Colorado.

Figure 5 shows that the oil fields of the Sundance in Wyoming and Colorado occur only where the marine basin overlaps the Entrada sandstone. The fields are confined to the southeastern part of the basin and the conditions under which source beds were formed may have been controlled by successive positions of the shore lines as the sea advanced or retreated. These, presumably, were roughly parallel.

In northwestern Colorado there are three structures close together. Two of these, Iles and Moffat, produce oil from the Sundance, and the third, Thornburg, had a showing of oil at the south end and a small amount of gas on top. There is a very marked thinning of the black marine shales of the Sundance toward the southeast in this locality and although there may be some other explanation of the lack of oil at Thornburg, it is possible that it is due to lack of source beds.

It is quite evident that production in the Sundance sand is not to be expected except where the sand and overlying marine beds are both present. In other parts of the marine basin other reservoir rocks must be present, as in the fields of northern Montana. Sands higher in the Sundance formation may occur, as in the Lance Creek field, and involve a separate stratigraphic problem.

There are other possibilities in the Jurassic rocks. The Navajo sandstone (Nugget of southwestern Wyoming) is overlain by the marine beds of the Carmel formation and its equivalents. The Carmel represents a period of marine invasion older than that of the Sundance and is much more restricted in extent. There are great variations in the distribution of all of the Jurassic formations. The Carmel may play out, bringing the Entrada and Navajo together. The two may thin to one unit overlain by the Sundance, as is probably the case in

[34] Ross L. Heaton, *op. cit.*, pp. 127–29.

the so-called Nugget sandstone of parts of Utah and Colorado. Moreover these sands may be found to wedge out updip in the presence of marine beds at such localities as Uinta, Green River, and Bighorn basins.

Harley dome, in east central Utah, produces gas from the Entrada and is outside the marine basin. The gas is 84 per cent nitrogen and 7 per cent helium with small amounts of ethane and methane. It resembles the non-inflammable gas fields of the Triassic in northeastern New Mexico in that it is on a Carboniferous positive element and there are no beds associated with it which have the appearance of containing source rocks.

LATE LOWER CRETACEOUS AND UPPER CRETACEOUS

DAKOTA GROUP

Figure 6 shows the maximum extent of the Dakota group of sandstones and shales and the overlying Benton formation. In the so-called Dakota group are included the Cloverly of Wyoming and the Kootenai of Montana as well as the upper sandstone, the Muddy or Newcastle, and the intervening shales. Lower Cretaceous beds are included in the Cloverly and Kootenai and probably also in the Dakota group of other localities. The map is therefore of very general nature and includes an extensive time interval. The sandstones of this group are not blanket sands over the whole area but comprise a great series of overlapping lenses, the limits of which may be determined by detailed work. The history of sedimentation in this period was one of oscillatory movements of varying duration resulting in alternations of sandstones and shales, both marine and continental, and lasting well into Benton time. Examples are the sands in the Mowry shale of Wyoming and the Blackleaf sandy member of the Colorado shales of Montana.

The distribution of the fields shown on the map indicates a widespread occurrence of source beds, but it must be remembered that it is probably not possible to correlate such beds as to age, except locally, even though they may be apparently at the same stratigraphic position. Detailed studies may show, for instance, that there are many distinct horizons of source beds in the Benton shale alone, each having definite geographic limits. These studies may explain the lack of oil in good structures in the same general localities as producing fields, such as in central Montana and northwestern New Mexico. There are, of course, other explanations, but they are not proved simply because they seem to be obvious.

In the Dakota group and associated formations, we have again

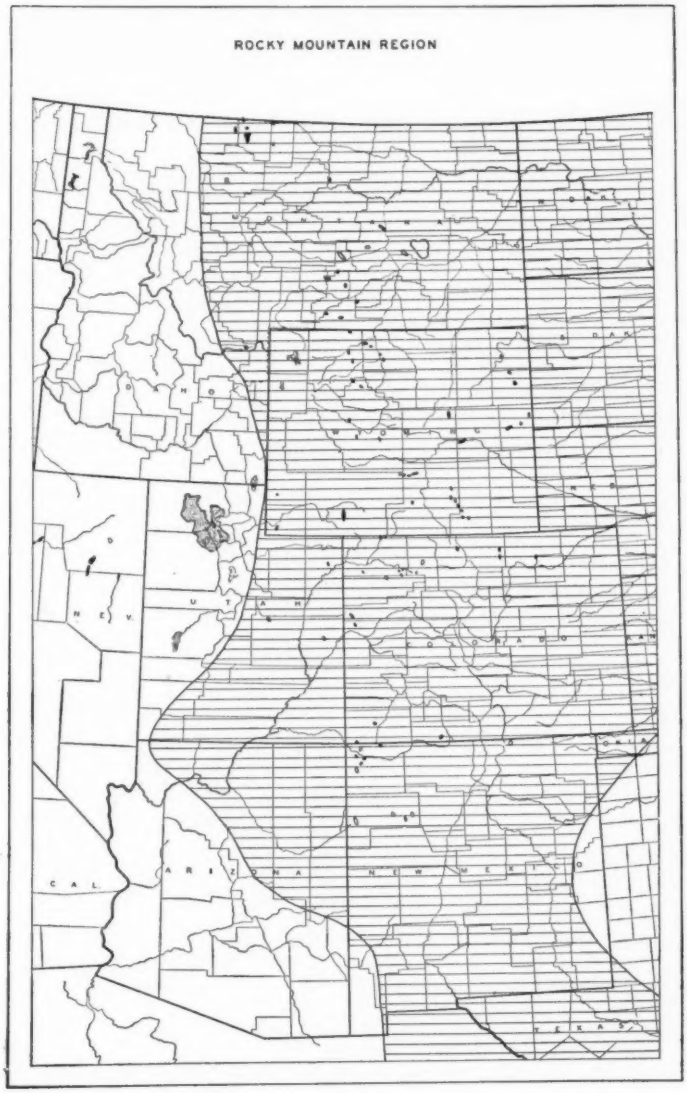

FIG. 6.—Paleogeography of late Lower Cretaceous and early Upper Cretaceous. Oil and gas fields in solid black. Outstanding structures proved dry are outlined in black.

the possibilities of wedging sands under the proper structural conditions, as in the Cut Bank and Osage fields. The northern Montana fields, unlike those in the remainder of the Rocky Mountain region, probably have their source beds in the underlying Jurassic rocks. The fresh-water Morrison beds, which usually overlie the marine Jurassic, are absent in that area.

FRONTIER

In Figure 7 the extent of the marine basin is shown to be the same as in Figure 6. A line has been added to show the eastern limits of the thick Frontier sandstones, which have their counterpart in the Ferron sandstone series of central Utah. A thin, commonly fine-grained sandstone, which is equivalent to a part of the typical Frontier, extends over wide areas. It is given the name Frontier in northwestern Colorado, Ferron in eastern Utah, Tocito in New Mexico, Carlile in eastern Colorado, and Codell in Kansas. It has small production in two or three places, but in many localities it emits a fetid odor when broken.

The Frontier production is apparently limited by the extent of the thicker phase of that formation. Production shown outside that area is either shale oil or from beds slightly higher or lower than the Frontier.

Stratigraphic traps may be found in the Frontier sands where they wedge out updip at such localities as in the Powder River, Laramie, and Uinta basins.

PIERRE

Periods of sandstone deposition recurred from time to time throughout Upper Cretaceous time. The source of materials was at the west and the wedges of sandstone extended various distances eastward. One of the outstanding examples of sandstone deposition is represented by the Mesaverde formation and its equivalent, the Judith River formation of Montana. These formations represent a break in the long period of shale deposition in Pierre time. In some localities 3,000–4,000 feet of sandstones, shales, and coals accumulated as continental or brackish-water deposits overlain by the Lewis or Bearpaw shales and underlain by the Mancos, Steele, or Claggett shales, all Pierre equivalents.

The area of Pierre deposition is shown in Figure 8 as somewhat more restricted than that of Benton time. The map also shows the approximate eastern limit of typical Mesaverde deposits and the area still farther east in which equivalent sandstones thinned considerably and were deposited under marine conditions. These are represented

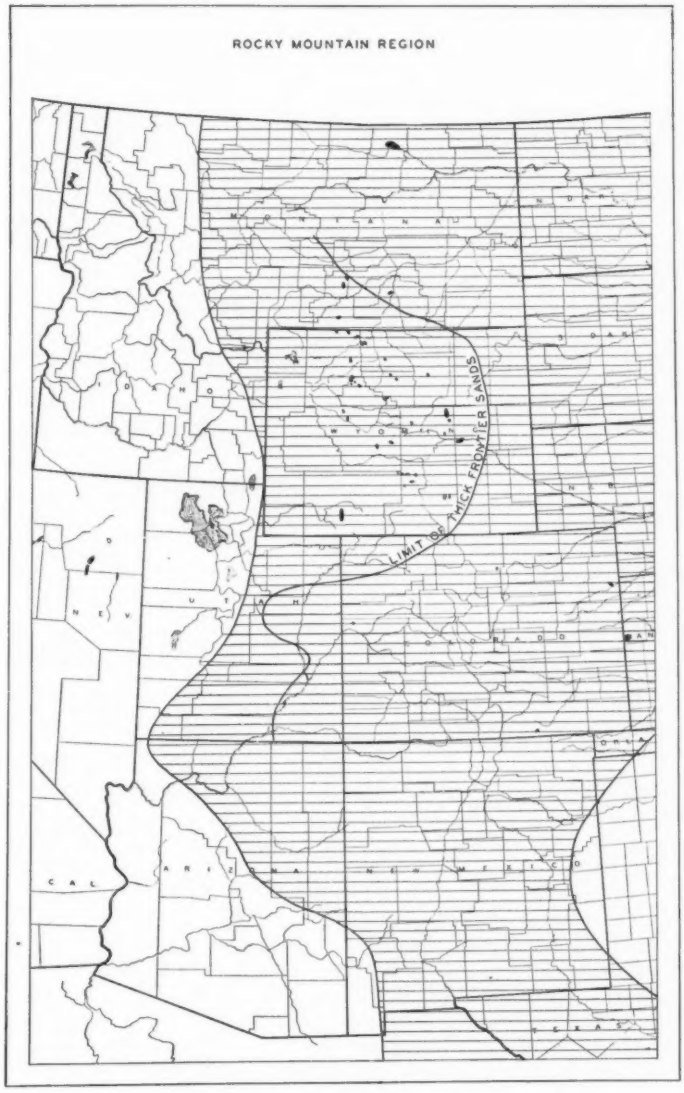

FIG. 7.—Paleogeography of late Benton or Frontier time. Oil and gas fields in solid black.

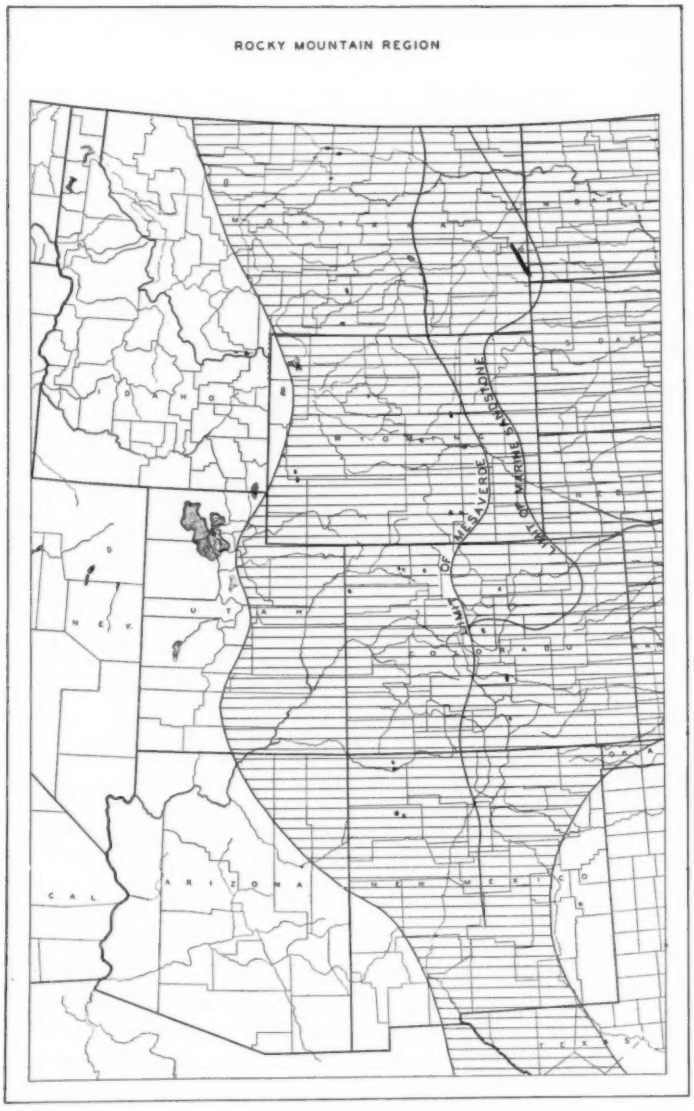

FIG. 8.—Paleogeography of late Upper Cretaceous. Oil and gas fields in solid black.

by the Hygiene group of eastern Colorado and Wyoming and by the marine Judith River of Montana. They wedge out eastward and may have possibilities as stratigraphic traps in the Denver and Powder River basins and at the north end of the Black Hills uplift.

There is no important production from the Mesaverde group at present. Some gas is produced in northwestern Colorado from the lower members, presumably in close proximity to the marine shales of the Mancos formation. The fields shown outside the limits of the marine sandstones are shale-oil producers.

Another prominent sandstone member near the base of the Pierre produces gas in many localities in Montana. This is the Eagle sandstone. Production is all on closed anticlines, but it is yet to be explained why such prominent structures as Ingomar and Willow Creek fail to produce. A map of the eastern and southern limits of the Eagle would disclose interesting possibilities.

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VOL. 21, NO. 10 (OCTOBER, 1937), PP. 1268-1310, 10 FIGS.

WATER-INSOLUBLE RESIDUES IN ROCK SALT OF LOUISIANA SALT PLUGS[1]

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Baton Rouge, Louisiana

ABSTRACT

The concept that rock salt of the Gulf Coast salt plugs is virtually pure halite has been established on surprisingly meager data, and is contrary to what should be expected in the light of what is known of salt deposits in other parts of the world. The composition of Gulf Coast rock salt has direct bearing on the origin of cap rock.

The amount and character of water-insoluble residue has been determined for rock salt from 20 Gulf Coast localities, chiefly in Louisiana, and has been found to be much the same as that of the German occurrences. The residues average between 5 and 10 per cent by weight of the rock salt and consist largely of anhydrite grains, but the following minerals, in the order of abundance, have been found in one or more localities: dolomite, calcite, pyrite, quartz, limonite, hematite, hauerite, sulphur, celestite, marcasite, barite, kaolinite, gypsum, magnesite, danburite, boracite, and a new borate. Inclusions of brine, gas, oil, and sand are not uncommon in the salt plugs of the Gulf Coast. Petrographic analyses of the sand inclusions from Avery Island and Jefferson Island show that they differ from known sands of the Gulf Coast. Potash salts are present in 10 of the 21 salt plugs studied.

Petrographic analyses are to be made of cap rock from several of the salt domes studied in order to determine whether the distinctive minerals of the residues occur in the cap rock in such relationship as to indicate its formation by accumulation of water-insoluble residue from the salt.

INTRODUCTION

The rock-salt deposits of the Gulf Coast have long been objects of scientific interest and have been the subject of a great many discussions. Many of the articles which have been written about these deposits have been of a theoretical nature and very few of them have treated in any detail the actual mineral composition of the rock salt. In most instances the salt has been dismissed with the statement that it is virtually pure halite. Other rock-salt deposits than those of the Gulf Coast, however, have proved to be highly complex in composition. Very detailed studies of the German deposits have shown that they consist of a complex series of soluble and insoluble salts, and also contain various types of foreign inclusions. German geologists have for many years been of the opinion that the "gypshut" or cap rock which overlies some of the salt plugs has been formed through the solution of soluble salts and the accumulation of water-insoluble materials. This explanation has been rather widely accepted for all occurrences of salt-dome cap rock, although somewhat reluctantly for the Gulf

[1] Manuscript received, July 23, 1937.

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Coast because the rock salt of this region is considered to be much more nearly pure halite than that of other regions. The petrographic studies of the cap rock of Gulf-Coast salt domes made by Goldman (1925; 1933)[3] and Brown (1931) have shown that the anhydrite cap rock in particular contains minerals which are also known to occur in the salt plugs. However, the literature contains too little quantitative data on the composition of the rock salt to justify definite conclusions regarding a relationship between cap rock and salt plug.

In the course of studies of the cap rock of Louisiana salt domes,[4] the writer examined water-insoluble residues of rock salt from a few Gulf Coast localities, and became convinced that they are sufficiently complex in mineral composition to warrant detailed study. Consequently, during the past year, samples have been collected and studied from 20 localities—17 in Louisiana, two in Texas and one in Mississippi. The results of this study, together with such additional data as could be obtained from the literature, have been assembled in the present paper. For the purposes of comparison, rock salt from bedded deposits of the Kansas and New Mexico Permian and from the Michigan Silurian have been examined, and these data likewise are presented.

This study can be considered as little more than a preliminary treatment of a subject which needs much more attention. As has been indicated, the primary object has been to obtain data regarding the amount of insoluble residue present and to determine whether the mineral asemblage of the residues is sufficiently characteristic to permit its identification, if present in the cap rock. The need of more work is especially borne out if one considers that of the 134 localities in the Gulf Coast in which rock salt occurs,[5] not more than 30 of them, including those reported on in the present paper, have been the subject of even a preliminary study. Because of their importance in connection with cap-rock and other salt-dome problems, and in view of their complex mineral composition, these interesting bodies should be made the basis of detailed studies wherever feasible.

The present study has been made possible through the generous coöperation of the salt, sulphur, and oil companies operating in

[3] Complete references are listed in the bibliography at the end of the paper, arranged alphabetically according to authors, and according to date of publication where more than one reference is listed from the same author.

[4] Studies which are in progress at the School of Geology, Louisiana State University, results of which are to be published later by the Louisiana Geological Survey.

[5] Based on figures of Hanna (1934) and Sawtelle (1936), and including the recently proved Harang or Valentine, Marchand, and Henderson salt plugs in Louisiana, and the occurrences at Smackover, Arkansas, and in Lamar County, Mississippi.

Louisiana, and of the Research Division of the Louisiana Geological Survey.[6] The writer wishes also to acknowledge the assistance of R. Dana Russell, School of Geology, Louisiana State University, in making this study and in preparing the report. The photomicrographs in Plates 6–10 and Figs. 2 and 3 in Plate 4 were made by George Hickens, Freeport Sulphur Company, Port Sulphur, Louisiana.

PREVIOUS WORK

Rock salt was discovered in the Gulf Coast in 1862, at Petite Anse (Avery Island). Thomassy (1863) was the first to report on its composition, stating it to be 97.920 per cent sodium chloride. Hilgard also became interested in the occurrence soon after its discovery, writing about it as follows: "an analysis of a specimen of the salt which I obtained in 1863, showed its only impurity to consist of 0.120 per cent gypsum [undoubtedly anhydrite]" (1872). Goessman (1867) also published an analysis shortly after discovery of the rock salt, reporting 0.79 per cent $CaSO_4$ and 0.33 per cent water. These early reports seem to have gone far in establishing the idea that the rock salt of the Gulf Coast is virtually pure halite. The only early report of an appreciable amount of insolubles is that of Bolton (1888); but his determination of 7 per cent, chiefly gypsum (undoubtedly anhydrite), for the black bands at Avery Island seems to have received little attention.

Table I presents a summary of the published data on percentages of insoluble residue. The most detailed studies on rock-salt deposits of the Gulf Coast that have appeared are those of Harris and Veatch on the Five Islands of Louisiana. Although these authors described the "banding" or "striping" at Avery Island, Weeks Island, and Belle Isle, and knew that the darker bands contained appreciable amounts of anhydrite, they thought of the rock salt as essentially pure halite. Rogers (1918), Vaughan (1925), and Howe and Moresi (1931) have also discussed in some detail the rock salt of the Five Islands. The most complete treatment of residues and inclusions in the rock salt of the Gulf Coast is that of Hanna (1934); he presented data on the

[6] Because of their hygroscopic nature, rock-salt specimens are difficult to preserve, and consequently not easily obtainable. Without the whole-hearted coöperation received, a study of this kind would not have been possible. Samples of rock salt were contributed by: Avery Island Salt Mining Company; Carey Salt Company; Jefferson Island Salt Mining Company; Myles Salt Company; Potash Company of America; U. S. Potash Company; Jefferson Lake Oil Company; Freeport Sulphur Company; F. H. Lahee, Dallas, Texas; J. T. Grafton, Lake Charles, Louisiana; R. B. Grigsby, Lake Charles, Louisiana; H. V. Howe, Louisiana State University; C. C. Kemp, Lafayette, Louisiana; George May, Louisiana State University; C. L. Moody, Shreveport, Louisiana; W. C. Phalen, Syracuse, New York; K. T. Price, Port Sulphur, Louisiana; J. P. Smith, Carlsbad, New Mexico; Paul Weaver, Houston, Texas; and Fred S. Wright, Midland, Texas.

TABLE I

SUMMARY OF PUBLISHED DATA ON WATER-INSOLUBLE RESIDUE OR TOTAL IMPURITIES IN ROCK SALT OF GULF COAST SALT PLUGS

Locality	*Avery Island*							*Belle Isle*	*Brenham*	*Clay Creek*	*High Island*	*Hockley*		*Jefferson Island*	*Port Barre*	*Carlos*
Reference	*Thomassy (1863)*	*Hilgard (1872)*	*Goessman (1867)*	*Bolton (1888)*	*Lucas (1896)*	*Harris and Veatch (1899)*	*Harris (1908)*	*Veatch (1899)*	*Barton (1925, p. 755)*	*Lahee (1931)*	*Halbouty (1936)*	*Teas (1931)*	*Hanna (1934)*	*O'Donnell (1935)*	*Hanna (1934)*	*Rolshausen (1934)*
Percentage Water Insoluble	2.08	1.20	7.90	7.0 (Dark band)	1.03	7.0 (Dark band)	0.23 2.16	3.10 5.84 (Light and dark bands)	40.0 45.0 60.0	6.0 (Aver. for several cores)	1.3 to 3.0	11.26 6.46 5.55	15.3	1.0	1.0	Approx. 10.0

Estimates of Average Percentage of Water-Insoluble Residue

Harris (1908)	*Barton (1921)*	*Powers (1926)*	*Goldman (1931)*	*Hanna (1934)*
("Extremely pure")	1.0 to 2.0	1.0 to 4.0 Aver. 1.5 (East Texas)	10.0 ("Probably too high")	5.0 to 10.0

residue at Hockley and summarized previous work. Goldman (1933) discussed the reported occurrences of large inclusions and pointed out that little is known about these, excepting for the one at Avery Island. Occasionally, published reports on salt domes contain drillers' logs in which reference is made to inclusions of anhydrite, gypsum, and sand within the salt plug, generally near the boundaries. None of these inclusions, however, appears to have been made the subject of detailed studies. The presence of sand within the rock salt at Belle Isle, first noted by Lucas (1898), the "gypsum" inclusion at Drake to which Spooner (1926) refers, and the anhydrite lenses at Smackover (Spooner, 1932), seem to be generally accepted as definite occurrences, however.

Potash salts have been reported from several localities. These are listed in Table II. The only fossils known to occur in the salt plugs of the Gulf Coast are algae at Markham, Texas (DeGolyer, 1925; Tilden, 1930).

TABLE II

GULF COAST SALT PLUGS FROM WHICH POTASH SALTS HAVE BEEN REPORTED

Locality	*Bayou Bouillon, Louisiana*	*Boggy Creek, Texas*	*East Hackberry, Louisiana*	*Hawkinsville, Texas*	*Markham, Texas*
Reported by:	De Golyer (1931)	McLellan, Wendlandt and Knebel (1932)	Howe and Moresi (1931)	Hanna (1934)	De Golyer (1925); (also reported fossil algae)

The structure and composition of the bedded salt deposits in other parts of the North American continent, as well as those in other parts of the world, have received some attention. Crystals of anhydrite are included in the salt at Malgash, Nova Scotia (Powers and Hopkins, 1922), forming dark bands very like those found in the rock salt of the Gulf Coast. The rock salt of the New York and Michigan Silurian and of the Kansas Permian contains some anhydrite, although the total amount of insolubles is reported as being very small (see Phalen, [1919], for a brief treatment of all areas, Alling [1928], for New York, Rogers [1910], for Kansas, and Cook [1914], for Michigan). These deposits show some banding and, in addition, contain lenses of anhydrite, dolomite, sandstone and shale. The rock salt deposits of New Mexico contain beds of potash salts and also carry anhydrite as alternating layers and as disseminated grains (Schaller and Henderson, 1932). Dane (1935) states that the rock salt of Utah and Colorado, Pennsylvanian in age, is highly complex in composition.

Rock salt of the Mexican salt plugs has been referred to as similar to that of other salt-dome regions by Hartley (1917; also see Ver Wiebe, 1926). At Zipiquira, Colombia, rock salt occurs in a plug-like structure, and, according to Bücking (1911), contains microscopic crystals of pyrite and magnesite.

TABLE III

MINERALS FROM WATER-INSOLUBLE RESIDUES OF THE GERMAN ZECHSTEIN SALT DEPOSITS (MAINLY FROM BOEKE, 1910)

Mineral	*Remarks*
Anhydrite	Crystals and cleavage fragments in both younger and older Zechstein
Boracite	Crystals, from many localities
Carbonates of *Ca* and *Mg*	Crystals, common
Celestite	Crystals, from several localities
Goethite	Crystals from Kehmstedt, Brumby and Hanirode (also K. von Kraatz-Koschlau [1897])
Gypsum	Crystals in clays interbedded with rock salt
Hematite	Hexagonal plates, from many deposits
Hydrargillite	(Or gibbsite). Hexagonal plates
Magnesite	Douglashall (Ochsenius, 1890), occurrence questioned by Boeke (1910), but confirmed by Reidimeister (1912)
Magnetite	Crystals, but not common; as pseudomorphs after hematite (Mügge, 1913)
Pyrite	Crystals, from many deposits
Quartz	Good crystals, from many deposits
Rutile	As crystals; also reported by Mügge (1913) from Hildesia
Sulphur	Crystals from Stassfurt, Leopoldshall, and Hildesia
Sulphoborite	Crystals from Westeregelen
Calcite	Rhombohedral crystals (Reidemeister, 1912)
Dolomite	Rhombohedral crystals (Reidemeister, 1912)
Brookite (?)	Orthorhombic crystals, not definitely identified (Mügge 1913)
Chlorite	As sharp crystals, from Hildesia (Mügge, 1913)
Malachite	As sharp crystals, from Hildesia (Mügge, 1913)
Tourmaline	As sharp crystals, from Hildesia (Mügge, 1913)
Zircon	As sharp crystals, from Hildesia (Mügge, 1913)
Chalcocite	Crystals (Gloeckner, 1914)
Soluble *Cu* Salts	(Gloeckner, 1914)
Pyrrhotite	Crystals, from Aller-Nordstrum (Harbort, 1915)
Kaliborite	Monoclinic crystals and crystal aggregates (Bücking, 1895)

The Zechstein salt deposits of Germany have been studied in much greater detail than those of any other region. The manner of occurrence and the structure of the deposits have been described in several series of studies by Ochsenius, van't Hoff, Lachmann, Stille, Seidl and others. The data on insoluble residues of the Zechstein salt deposits have been summarzied by Boeke (1910), and these data, supplemented by such other as could be found, are given in Table III. Boeke estimates that the "older" Zechstein rock salt with the "Jah-

resringe," or alternate bands of light and dark gray salt, contains an average of 6 or 7 per cent of anhydrite grains, while the "younger," less banded rock salt is somewhat purer, containing about 2 per cent impurities. The rock salt in the Benthe salt stock carries about 5 per cent anhydrite in the form of grains, according to Lachmann (1912). Bretnütz (1911) presents analyses of the "younger" rock salt of Benthe showing impurities to be 3–7 per cent, and speaks of a gradational series of rock salt to anhydrite. Salt clays, sands, bedded dolomites, anhydrite, gypsum, and carbonaceous matter are found in many of the German deposits. Extensive study has revealed that the Zechstein deposits contain a variety of other types of inclusions in addition to those already mentioned. Among these are mother liquor (Boeke, 1910), carbon monoxide (Erdmann, 1919), carbon dioxide (Beck, 1912, and many others), hydrogen sulphide (Pfeiffer, 1889; Papp, 1911; Tolloczko, 1913); methane (Papp, 1910); petroleum (Graefe, 1911), and basalt (Naumann, 1910).

The rock salt of the Roumanian salt domes is reported to be 98–99.9 per cent sodium chloride, but it carries gypsum, anhydrite, clay, sands, and carbonaceous material scattered through it, in greatest abundance near the top of the salt body (Pustowka, 1929). Pronounced banding is present in the rock salt at Marosugra salt dome, Transylvania (Papp, 1913).

Powers (1928) has described the rock salt at Cardona in Suria, Spain, speaking of black bands which he ascribes to the presence of clays and anhydrite crystals.

The rock salt in the Persian salt domes has been described in some detail by Harrison (1930; 1931). He speaks of "salty gypsum," of pink, gray, and white rock salt, and of blocks of included rock "plucked" from beds beneath the deposit or picked up as the salt was intruded upward. The salt in the salt plug at Salif in Arabia is of a "curious dark grey appearance," according to Wade (1931, p. 326), and contains "well-formed microscopic crystals of anhydrite." The salt is mined here, and although the "greater part of the salt is said to be of great purity," varies from place to place, and some parts of the exposure can not be mined because of impurities.

In Kohat, India, there are extensive deposits of salt of a dark gray color, containing bituminous matter and an appreciable amount of anhydrite. The rock salt of the Salt Range of India is characterized by its association with the "salt-marl"—a poorly stratified deposit made up of dolomite, limestone, gypsum or anhydrite, and rock salt, in irregular masses (Wadia, 1926).

In general, then, it can be said that present ideas about the char-

acter of the rock salt of the Gulf Coast are based on a surprisingly meager amount of information. The little that is known about this rock salt comes from fairly detailed knowledge of one occurrence, Avery Island, and brief reports on some dozen others, whereas there are 134 localities in which rock salt has been found. The rock salt of other regions has been reported to be complex and variable in composition. Bedded deposits and salt plugs which have been extensively explored seem without exception to show this complexity and variability. Data which have been assembled from the present study indicate that the rock salt of the Gulf Coast salt plugs is far less simple than has been generally assumed. Before presenting these data, however, methods followed in obtaining them will be outlined briefly.

METHODS OF STUDY

Rock-salt samples or residues of sufficient size to be termed representative were obtained from only six of the 20 localities studied. Included in these six are the four Louisiana salt plugs at which salt is being mined—Avery Island, Weeks Island, Jefferson Island and Winnfield,[7] and in addition, Choctaw and Lake Washington (Grande Ecaille). Jefferson Island was the most completely sampled of any locality, since the mine material was supplemented by cores obtained from other parts of the salt plug during development of the sulphur deposit.[8] Material from Lake Washington likewise came from cores obtained during the drilling of sulphur wells.[9] The samples from Choctaw are chiefly residues resulting from the production of brine.[10] Material for the other localities is from cores taken during the drilling of oil and sulphur wells.

The water-insoluble residue of the rock salt was obtained by solution of known weights of clean, dry samples in cold, distilled water. The residue was caught in a filter paper, washed to remove all traces

[7] The writer collected samples at Winnfield in March, 1937, with the assistance of M. C. Mann, chemist, Winnfield, and of James Ford and Stanley McDonald, School of Geology, Louisiana State University. The other salt mines were sampled by the writer, with the aid of R. Dana Russell, of the faculty of the School of Geology, Louisiana State University, and J. Huner, Jr., Louisiana Geological Survey, in April, 1936.

[8] For discussions of the geology of Avery Island, Weeks Island, and Jefferson Island, see Harris and Veatch (1899), Harris (1908), Vaughan (1925), and Howe and Moresi (1931); O'Donnell (1935) has described the sulphur deposit at Jefferson Island. The geology of Winnfield salt dome will be discussed in a bulletin of the Louisiana Geological Survey on Winn and Caldwell parishes which is being prepared by J. Huner, Jr.

[9] This salt dome is discussed by Russell, Howe, *et al.* (1936).

[10] This material was made available to the writer through the coöperation of W. C. Phalen, Syracuse, New York, and of Carlton Bates, O. J. Hebert, and Leo Lassere, Baton Rouge, Louisiana.

of sodium chloride, dried at room temperature, and weighed. Gas was liberated during solution of many of the samples, and in one case (salt from Lake Hermitage salt dome) a 50-cc. sample was collected and has been analyzed.[11] A portion of the brine from each sample was concentrated and tested for the presence of potash (sodium-cobalt-nitrate test, see Curtman, 1934, p. 334). Additional samples of the concentrated liquor have been set aside for detailed chemical analyses. Fossils have not been found in any of the residues. It is possible that the film of finely divided red particles, chiefly hematite, which collects on the surface of the water during solution of the more impure rock salt, might prove to contain algae if subjected to the type of analysis made by Tilden (1930). The weight percentages of water-insoluble residue for each sample are presented in Table IV. Duplicate specimens are on file in the museum of the School of Geology at Louisiana State University for those localities from which sufficient material could be secured.

Examination of the residues proved them to consist almost entirely of microscopic grains of anhydrite, excepting in the case of the red "sandstone" inclusions, and of the residue from Choctaw. For this reason, and also because separation of the residues into light and heavy separates was not feasible, as virtually all minerals present are heavy minerals, the residues were examined under a binocular microscope for rarer minerals. These minerals were then identified under the petrographic microscope. The average mineral composition for each locality is given in Table V. Plates 1–5 are photomicrographs of some of the minerals.

The samples of rock salt containing red "sandstone" inclusions were first treated in the same manner as the other samples, since the cementing material is chiefly *NaCl*, and possibly other soluble salts. The residue which was obtained was then treated with 1:1 *HCl* for 30 minutes at a temperature just below 212°F. in order to remove the iron-oxide stain on the grains and to break down calcite- or dolomite-cemented aggregates. Following this, the sample was thoroughly washed and dried. Slides of light and heavy minerals were then prepared in accordance with the procedure outlined by Russell (1936). With the aid of a petrographic microscope equipped with mechanical stage, frequency percentages were determined for the 150- and 200-mesh for both light and heavy separates, and in addition, for the whole sample and 300-mesh in the case of the heavy separate and for the 100-mesh of the light separate. These sizes of material were chosen

[11] The results of this analysis will be published in a later paper.

on the basis of their importance in the mechanical analysis of the sands (Table VI). The results of the petrographic analyses of these sands are presented in Table VII.

Thin sections were prepared for specimens of banded rock salt, "black" salt from near the anhydrite-rock salt contact, and for the red "sandstone" inclusions. These were also studied under the petrographic microscope, and the results are treated briefly under the discussion of sand inclusions. Photomicrographs of some of these slides appear in Plates 6–10.

OCCURRENCE OF ROCK SALT

The rock salt of the salt plugs studied is all of the same general character. As revealed in the mines and to a lesser extent in well cores, it is massive and compact, and is of granular structure. The individual grains or crystals are somewhat elongate and average $\frac{1}{4}$–$\frac{1}{2}$ inch in length, rarely exceeding 2 inches. Some of the larger ones have curved faces many of which have a sheared or fibrous appearance. Rock cleavage is fairly well developed, generally along horizontal planes, although high-angle cleavage appears in some of the well cores.

The pronounced, almost vertical, dark bands or "pencil stripes," strikingly developed in the rock salt of the mines and in many of the well cores, is almost as marked a feature as the compactness. These bands have virtually the same attitude in all parts of several of the mines. At Avery Island they have an attitude of E.-W. 85° S. (apparent dip). The apparent dip of the bands is 85° throughout the mine at Weeks Island, but the strike varies from N. 45° W. to N. 20° E., and similarly the strike at Winnfield mine varies from 10° to 30° E. of N. with an apparent dip of 65°–70° S. These dark bands average from one to four inches in width, some attaining an 18-inch width. Light bluish gray, nearly colorless rock salt occurs between the darker salt in bands one to three times the width of the dark bands. Some of the dark bands are quite distinctive and can be traced from room to room in the mines.

The bands appear to be part of a system of slightly tilted, very steep folds. Series of similar appearing bands that are separated by an interval of several feet at the floor of the mine converge to form crests of folds at the ceiling. This same structural condition is also indicated by the inclusions of red "sandstone" at Avery Island and Jefferson Island and the lenses of anhydrite sand at Weeks Island and Winnfield, as they have the same attitude as the dark bands. Intensive

overfolding and faulting, as well as plicating, are suggested by the distorted condition of some of the bands.

Analyses of both the light and dark gray rock salt (Table IV), show that the dark bands contain an appreciably greater amount of water-insoluble residue (chiefly anhydrite grains). This fact was first pointed out by Bolton (1888) and undoubtedly explains the darker appearance of these bands. There is a suggestion of alignment of the larger, elongate anhydrite grains parallel with the banding in thin sections of rock salt from the dark bands. This same tendency is shown by the anhydrite grains in the anhydrite lenses, and in addition, some of the larger grains are crushed, with the resulting cleavage fragments arranged in trains paralleling the bands.

The salt in parts of the Winnfield and Weeks Island mines is less well compacted than the average. At Winnfield, a rather impure, loosely compacted type is referred to as "soft salt," and the anhydrite grains contained in it range from medium- to coarse-sand size. There is also a "hard salt" at Winnfield that on the average contains much less water-insoluble residue than the "soft salt." The anhydrite grains in this "hard salt" are of fine-sand size and they are concentrated in lenses, composed almost entirely of these grains, that break out of the enclosing rock salt as tough, smooth-surfaced "slabs" of a fraction of an inch to several inches in thickness. Some of these "slabs" or lenses are extensive and are parallel with the general banding in the rock salt. These "slabs" are also banded within themselves, due either to very thin veins of rock salt or to concentrations of iron-bearing minerals. Shear zones are developed where the "soft salt" is in contact with the "hard salt," and some recrystallization has taken place along these zones.

Liquid and gas inclusions are present in the rock salt of all the mines. Brine from a "wet spot" at Jefferson Island has been analyzed (Table VIII) and its composition indicates that it is "mother liquor." A zone of "hard salt" containing considerable "slab" anhydrite, encountered at the northwest, north, and northeast limits of the Winnfield mine, seeps brine and gas in appreciable quantities. The brine and gas seep upward, apparently moving parallel with the banding. The brine contains the ferrous ion, suggesting that it is also "mother liquor"; the gas is thought to be chiefly carbon dioxide, with some inert gas present. A well drilled about 600 feet below the level of the mine at Winnfield encountered similar brine and gas under a pressure of 225 pounds per square inch. A gas blowout occurred in the ceiling of one room at Winnfield, and was of sufficient force to form a cavity of considerable size. "Hard salt" from this mine, and similar

appearing salt from other salt plugs, contains gas which is under sufficient pressure to cause "popping" when the salt is dissolved. The odor of hydrogen-sulphide gas is discernible in freshly mined salt from one of the dark bands at Avery Island. Pockets of oil-stained salt occur in the Avery Island and Jefferson Island mines. A light amber-colored oil, accompanied by methane gas, seeped from these pockets when they were first uncovered. When this oil-stained salt is dissolved, the oil, which occurs as small drops in the halite crystals, accumulates as a film on the surface of the water.

The distribution of the water-insoluble residue in different parts of the same salt plug, as well as in the various salt plugs, is characterized by considerable irregularity. Hanna (1934) notes that the rock salt of the periphery, as well as that of the upper part of the salt plug, seems to contain more residue than the interior parts of the salt plug in some instances, and less in others. This is borne out by the analyses in Table IV. Drillers report that at Jefferson Island and Lake Washington the top of the salt plug is separated from the cap rock by a cavity of a foot or two and that the first salt is of a "mushy" type, containing a considerable amount of anhydrite sand. Cores of this material were not available, but samples of anhydritic "black salt" representing the first cores which could be taken from several wells at Jefferson Island, are of banded light and dark gray salt very like that from the mine.

An estimate of the average amount of insoluble residue present in the rock salt of any one salt plug, or in Gulf Coast salt plugs in general, is difficult to make because of this irregularity in distribution. It can be stated definitely, however, that there is considerably more than the generally accepted figure of 1–2 per cent. This is evident from a study of the data presented in Table IV for the better sampled localities. The figure of 1–2 per cent should also be considerably increased for the salt mines, as selective mining is practiced in all of them, and, in addition, the mined salt is subjected to hand picking or screening in order to remove the visibly impure salt. This last factor increases the total amount of residue from one to several per cent. Based on such data as are available, therefore, it appears that the figure which has been given for the German salt plugs, 5 per cent, is certainly not too high for the rock salt of the Gulf Coast, and that probably the figure suggested by Hanna (1934), 5–10 per cent, is a reasonable approximation.

Residues of rock salt from bedded deposits.—The Permian rock salt of Kansas[12] is more coarsely crystalline than that of the Gulf Coast.

[12] The samples studied are from a Hutchinson, Kansas, mine, and a Lyons, Kansas, mine.

TABLE IV

WEIGHT-PERCENTAGE OF WATER-INSOLUBLE RESIDUE IN SALT PLUGS STUDIED

Salt Dome	*Sample Number*	*Description of Rock Salt Sample*	*Weight Per Cent Residue*
Anse La Butte	1	Stanolind Oil—Patin No. 1, 4,601–4,603 feet; bluish gray, nearly colorless	0.2
	2	Stanolind Oil—Patin No. 1, 4,641–4,643 feet; gray, loosely compacted	2.8
Avery Island	1	E. part of mine; light and dark gray banded	3.3
	2	N.E. part of mine; light and dark gray banded	4.7
	3	S.E. part of mine; light and dark gray banded, chiefly dark gray	7.0
	4	E. part of mine; light gray band with H_2S odor	2.7
	5	S.S.E. part of mine; light and dark gray banded	3.5
Bayou Bleu	1	Standard Oil—Wilberts and Son No. 6, 2,807–2,825 feet bluish gray, compact	0.8
Choctaw	1	Solvay Process—No. 1, 657–1,064 feet; composite sample, powdered	1.7
	2	Solvay Process—No. 1, 1,065–1,448 feet; composite sample, powdered	1.5
	3	Standard Oil—Wilbert's Myrtle Grove No. 1, 2,566–2,575 feet; gray, granular	3.9
Darrow	1	Humble O. & R.—Community No. 5, 5,448–5,456 feet; gray, granular	2.6
	2	Humble O. & R.—Community No. 9, 5,633–5,638 feet; bluish gray, granular	2.0
	3	Humble O. & R.—Community No. 9, 5,674–5,684 feet; bluish gray, granular	2.0
	4	Humble O. & R.—Community No. 13, 5,672–5,682 feet; bluish gray, granular	1.9
	5	Rio Bravo Oil—Gumbel No. 1, 6,035–6,041 feet; gray, granular, compact	7.0
E. Hackberry	1	Stanolind Oil—Gulf Farm No. 21B, 6,948–6,965 feet; small colorless crystals	0.5
	2	Gulf Production—Erwin "A" No. 22, 6,201–6,206 feet; light gray, granular	3.5
	3	Gulf Production—Erwin "A" No. 23, 5,500–5,505 feet; gray, granular (methane gas)	6.4
Garden Id. Bay	1	Texas Co.—State No. 7, 2,107–2,117 feet; small colorless crystals	1.6
Jefferson Id.	1	S.W. part of mine; yellow, oil-stained, flecked with gray	1.2
	2	N.W. part of mine; bluish gray, nearly transparent, coarsely crystalline	1.1
	3	E. part of mine; bluish gray, compact	1.9
	4	S.E. part of mine; brown, granular, loosely compacted	1.8
	5	N.E. part of mine; gray, flecked with dark gray	2.3
	6	Jefferson L. Oil—State No. 151; bluish gray; granular, well compacted	1.0
	7	Jefferson L. Oil—State No. 230, 888–898 feet; dark gray	12.6

TABLE IV—*Continued*

Salt Dome	*Sample Number*	*Description of Rock Salt Sample*	*Weight Per Cent Residue*
Jefferson Id.	8	Jefferson L. Oil—State No. 238, 867–874 feet; dark gray	15.0
	9	Jefferson L. Oil—State No. 264, 903–913 feet; dark gray, with narrow bands	15.0
	10	Jefferson L. Oil—State No. 272, 820–824 feet; dark gray, banded	20.0
	11	Jefferson L. Oil—State No. 296, 884–890 feet; dark gray	12.5
Jennings	1	Superior Oil—Rhodes No. 1, 3,908–3,916 feet; gray, granular, compact	3.0
L. Hermitage	1	Humble O. & R.—State No. 1, 4,013 feet; light gray, granular, compact	3.4
	2	Humble O. & R.—State No. 1, 4,013–4,276 feet; gray, with knots of anhydrite sand	6.2
	3	Humble O. & R.—State No. 1, 4,276–4,283 feet; gray, with stringers of anhydrite	4.0
L. Washington	1	Freeport Sulphur—Cockrell & Moran No. 7, 1,588–1,589 feet; light gray, granular	1.0
	2	Freeport Sulphur—Cockrell & Moran No. 59, 1,580–1,714 feet; light gray, granular	3.6
	3	Freeport Sulphur—Cockrell & Moran No. 61, 1,630–1,680 feet; gray, granular, compact	4.1
	4	Freeport Sulphur—State No. 1,035, 1,650 feet; bands of anhydrite sand	5.0
	5	Freeport Sulphur—Misc.; gray, with patches of anhydrite sand	5.0
	6	Humble O. & R.—State No. 2, 1,807–1,830 feet; light gray, granular, loosely compacted	2.2
	7	Humble O. & R.—Cockrell & Moran No. 23, 4,780–4,783 feet; light gray, granular	3.0
	8	Humble O. & R.—Cockrell & Moran No. 23, 4,789–4,809 feet; gray, granular	5.0
	9	Humble O. & R.—Cockrell & Moran No. 23, 4,809–4,834 feet; gray, anhydrite sand incl.	7.8
	10	Humble O. & R.—Cockrell & Moran No. 23, 4,860–4,867 feet; gray, granular,compact	5.0
	11	Humble O. & R.—Cockrell & Moran No. 23, 4,897–4,903 feet; gray, with anhydrite sand	11.9
	12	Humble O. & R.—Cockrell & Moran No. 23, 4,933–4,938 feet; light gray, granular	3.9
	13	Humble O. & R.—Cockrell & Moran No. 23, 5,048–5,053 feet; light gray, granular	3.0
	14	Humble O. & R.—Cockrell & Moran No. 23, 5,213–5,252 feet; bluish gray, granular	1.8
Sikes	1	Ohio Oil—Rollin No. 1, 4,145 feet; gray, with vertical bands of anhydrite sand	7.2
Sulphur	1	Union Sulphur—miscellaneous; light gray, compact, flecked with dark gray	4.0
Venice	1	Tidewater Oil—Manhattan Fruit No. 1; yellow, oil-stained	4.0

TABLE IV—*Continued*

Salt Dome	*Sample Number*	*Description of Rock Salt Sample*	*Weight Per Cent Residue*
Weeks Island	1	N.E. part of mine; granular, bluish gray, flecked with gray impurity	1.3
	2	N.E. corner of mine; nearly colorless, with gray flecks	2.6
	3	Tailings; gray, "soft salt" banded with anhydrite sand	11.2
	4	N.W. part of mine; dark, brownish gray "hard salt" (methane gas)	24.0
White Castle	1	Shell Oil—Shingle No. 1, 5,041–5,056 feet; nearly colorless, granular	1.9
	2	Shell Oil—Shingle No. 2, 5,211–5,213 feet; gray, granular, fairly well-compacted	2.5
Winnfield	1	Mine sample; banded light and dark gray, granular and compact	8.7
	2	From near shaft; gray "soft salt," with bands of coarse anhydrite sand	29.3
	3	Mine sample; bluish gray, coarsely crystalline "hard salt"	1.5
	4	Mine sample; dark gray, banded, "hard salt"	8.0
	5	"Slab" anhydrite from lens in "hard salt"	81.8
	6	Series of 25 samples of salt as mined, ranging from 0.3 to 8.0 per cent, average	2.5
	7	Series of 25 samples of salt as mined, ranging from 0.1 to 8.0 per cent, average	1.7
Hoskins, Tex.	1	Freeport Sulphur—Hoskins Mound No. 365, 2,069 feet, bluish gray, granular, compact	4.2
Lamar, Miss.	1	Sun Oil—Scanlon & Semmes No. 1, 2,524–2,543 feet; gray, vertical bands of anhydrite sand	19.5
	2	Sun Oil—Scanlon & Semmes No. 1, 2,524–2,543 feet; light gray to bluish gray	3.2
	3	Sun Oil—Scanlon & Semmes No. 1, 2,564–2,583 feet; gray, with bands of anhydrite sand	25.0
	4	Sun Oil—Scanlon & Semmes No. 1, 2,564–2,583 feet; bluish gray, faintly banded	0.5

The banding is of two types. That in the main part of the deposit is of the same type as that in the Gulf Coast, with the attitude horizontal. A composite sample of this type, including both light and dark bands, contained 5.7 per cent of insoluble residue, which consisted entirely of anhydrite grains. The second type of banding occurs near the base of the salt beds and is formed by inclusions of clay, with large crystals of halite developed across the bands. Negative crystals containing brine and gas characterize this second type. Rogers (1910) has reported the following minerals associated with rock salt from dump piles of two Kansas salt mines: anhydrite, gypsum, dolomite, quartz, celestite, and pyrite.

The salt occurring in association with the potash salts mined in

New Mexico[13] contains inclusions of carbonates, quartz, anhydrite, hematite (minute flakes), and clay (submicroscopic particles), in the order of their abundance. Samples of this salt, from near the zone of the potash salts, contain 1–2 per cent of residue. It is also a coarsely crystalline, massive rock salt. Schaller and Henderson (1932) state that anhydrite is generally second in abundance to halite, and clays are third. They report, in addition to the minerals previously mentioned, celestite, magnesite, pyrite, and opal. Inflammable gas and a gas high in nitrogen have been encountered during mining operations.

Rock salt of Silurian age from Detroit, Michigan, is very coarsely crystalline and the banding which is present is of the same type as that in the basal part of the Kansas beds. It contains inclusions of gas, liquid, massive dolomite, clay, carbonaceous matter, quartz crystals, and a sulphate. The sulphate occurs in minute flakes giving an optic normal interference figure. Its properties check those of anhydrite, except for refractive indices, which are slightly lower. It may be partially hydrated $CaSO_4$.

MINERALS OF GULF COAST ROCK SALT

The results of the studies of the water-insoluble residues, other than the red "sandstone" inclusions, are summarized in Tables IV and V. The minerals of the residues are characteristic and for this reason will be described briefly. Those of the red "sandstone" inclusions, for which data are presented in Tables VI and VII, are typical detrital minerals, and the reader is referred to Milner (1929) for descriptions of them.

The soluble material of the rock salt is chiefly halite. The properties of this mineral are well known and need not be reviewed here. Potash salts are known to be present only through chemical tests. Upon evaporation of a Choctaw brine that gave a definite potash reaction, minute, opaque crystals having a refractive index sufficiently low to be sylvite, were formed within halite crystals. Some of the red, opaque cementing material in the inclusions of red sand may be a potash clay, as the brine resulting from solution of these inclusions gave a strong positive reaction for potassium.

Anhydrite ($CaSO_4$).—Ninety-nine per cent of most of the residues consists of nearly colorless, microscopic grains of anhydrite, resulting in the typical gray or bluish gray color of the residues. The anhydrite occurs as cleavage fragments and as subhedral to euhedral crystals, varying in size from microscopic up to as much as 14.0 mm. in great-

[13] Salt specimens from the potash mines near Carlsbad, New Mexico, and from wells drilled in West Texas, were studied.

TABLE V

CHECK LIST OF MINERALS IN WATER-INSOLUBLE RESIDUES OF SALT PLUGS STUDIED

More Common Minerals (in order of abundance)	*Anse La Butte, La.*	*Avery Island, La.*	*Bayou Bleu, La.*	*Choctaw, La.*	*Darrow, La.*	*East Hackberry, La.*	*Garden Id. Bay, La.*	*Jefferson Id., La.*	*Jennings, La.*	*Lake Hermitage, La.*	*Lake Washington, La.*	*Sikes, La.*	*Sulphur, La.*	*Venice, La.*	*Weeks Island, La.*	*White Castle, La.*	*Winnfield, La.*	*Hockley, Tex.*	*Hoskins Mound, Tex.*	*Lamar County, Miss.*
Anhydrite	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dolomite	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Calcite	x	x	x	x	x	x		x		x	x	x	x		x	x	x	x		x
Pyrite	x	x	x	x		x		x	x		x				x	x	x	x	x	
Quartz	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Limonite	x	x		x			x	x			x				x		x	x	x	x
Hauerite	x	x		x			x	x			x				x					
Sulphur		x		x				x			x		x						x	
Hematite		x		x				x									x	x		
Celestite											x		x		x				x	
Barite								x									x			
Marcasite				x				x												
Kaolinite		x						x												
Other Inclusions			•																	
Potash salts	Tr.	x	x	x	Tr.			x			x			Tr.	x	Tr.				
Oil		x		x				x		x				x	x					
Gas		x		x	x	x	x	x		x	x		x	x	x	x	x			
Quartz sand	x	x		x				x			x		x	x	x					

est dimension; the average is a fine- to medium-sand size ($\frac{1}{8}$–$\frac{1}{2}$ mm.). The anhydrite grains, as a rule, are quite clear and colorless, although here and there they contain inclusions. These inclusions consist of smaller anhydrite grains, grains of quartz, pyrite, dolomite, sulphur, gas and liquid, and carbonaceous matter. A few of the samples are made up of grains carrying sufficient carbonaceous matter to make the residue dark gray. Certain of the samples contain worn, frosted and serrated grains which appear to have been subjected to solution. The grains from rock salt containing considerable residue (15 per cent or more), or with knots or bands of included material, appear to be composed of a high percentage of microscopic cleavage fragments, some of which form loosely cemented aggregates as much as a centimeter in diameter. Solution seems to have had greater effect on grains from the more impure rock salt than it has on those from the purer samples.

The greater part of the grains in a majority of the samples occur as somewhat irregular cleavage fragments, tabular parallel to the $\overline{001}$ cleavage, with the $\overline{010}$ sometimes favored and $\overline{100}$ subordinate. The crystals which are present commonly occur as the short "stem-shaped," orthorhombic forms described by Reidimeister (1912), which are elongate parallel to *a* or *b* and striated parallel to *a* due to the partial development of brachydomes and side pinacoids. A few of the crystals show partial development of macrodomes.

The other properties of the anhydrite are those listed for the pure mineral by Winchell (1933). Plate 1 illustrates typical anhydrite grains.

Carbonates.—The carbonates of calcium, magnesium, and iron are common in nearly all of the residues and constitute as much as 10 per cent in one case (a residue from Choctaw). They occur as perfect crystals, generally rhombohedrons, of varying chemical composition. The following species have been separated on the basis of refractive indices: dolomite (as the subspecies magnesiodolomite and ankerite), calcite, and magnesite. Typical carbonate crystals are illustrated in Plate 2.

Dolomite ($Ca, Mg\,[CO_3]_2$).—The subspecies of dolomite are the most important of the carbonates, and occur in relative abundance in most of the samples. Both the magnesiodolomite and the ankerite occur typically as transparent to translucent, simple or twinned, rhombohedral crystals, with uncurved faces, varying in size from 0.1 mm. to 1.0 mm. Occasionally, the base $\overline{0001}$, the positive rhombohedron $01\overline{1}1$, and negative rhombohedron $01\overline{1}2$, are present on a single crystal, and in the case of three of the residues from Choctaw, modify the

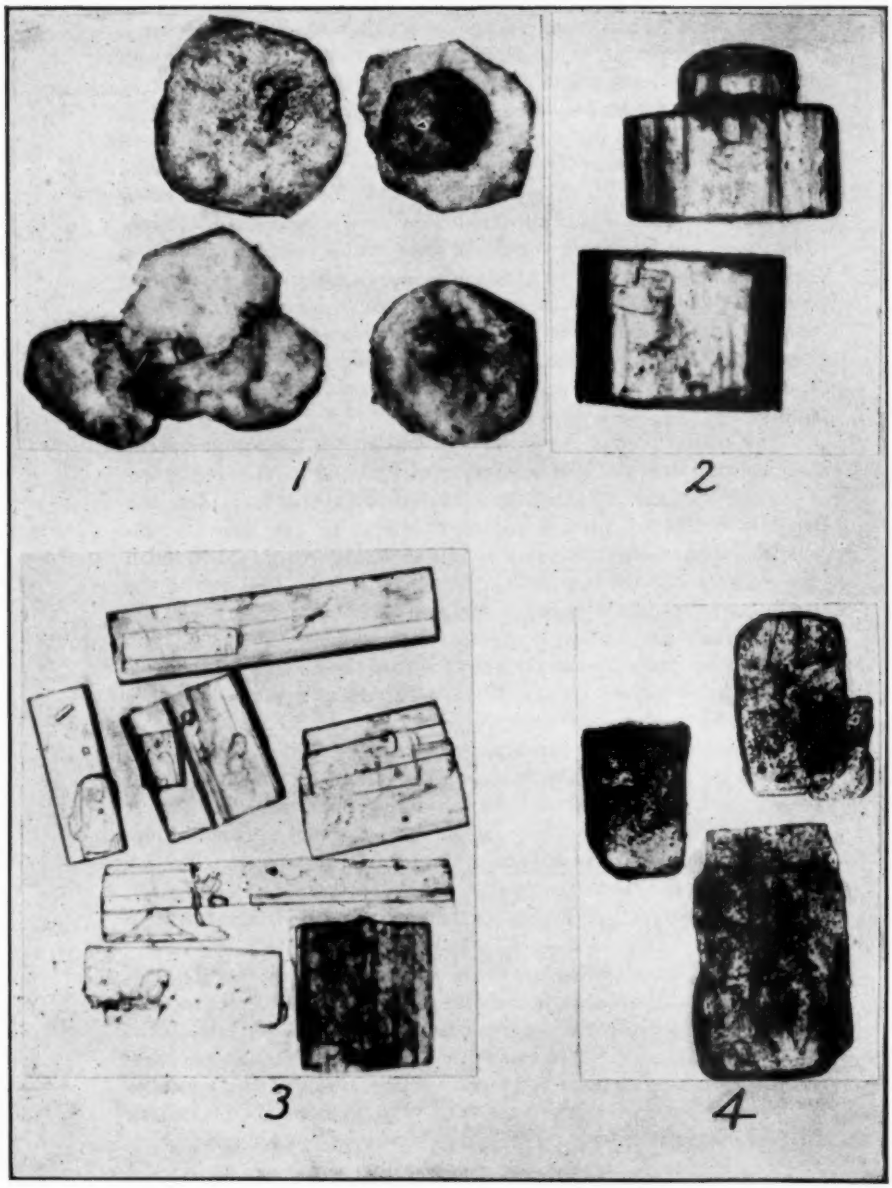

PLATE 1.—FIGS. 1 and 2. Stem-shaped anhydrite crystals from Sulphur residue lying on 100 (Fig 1.) and 010 or 001. ×44.
FIG. 3. Cleavage fragments of anhydrite from East Hackberry residue. ×35.
FIG. 4. Anhydrite grains with inclusions of carbonaceous matter, from Jefferson Island residue. ×30.

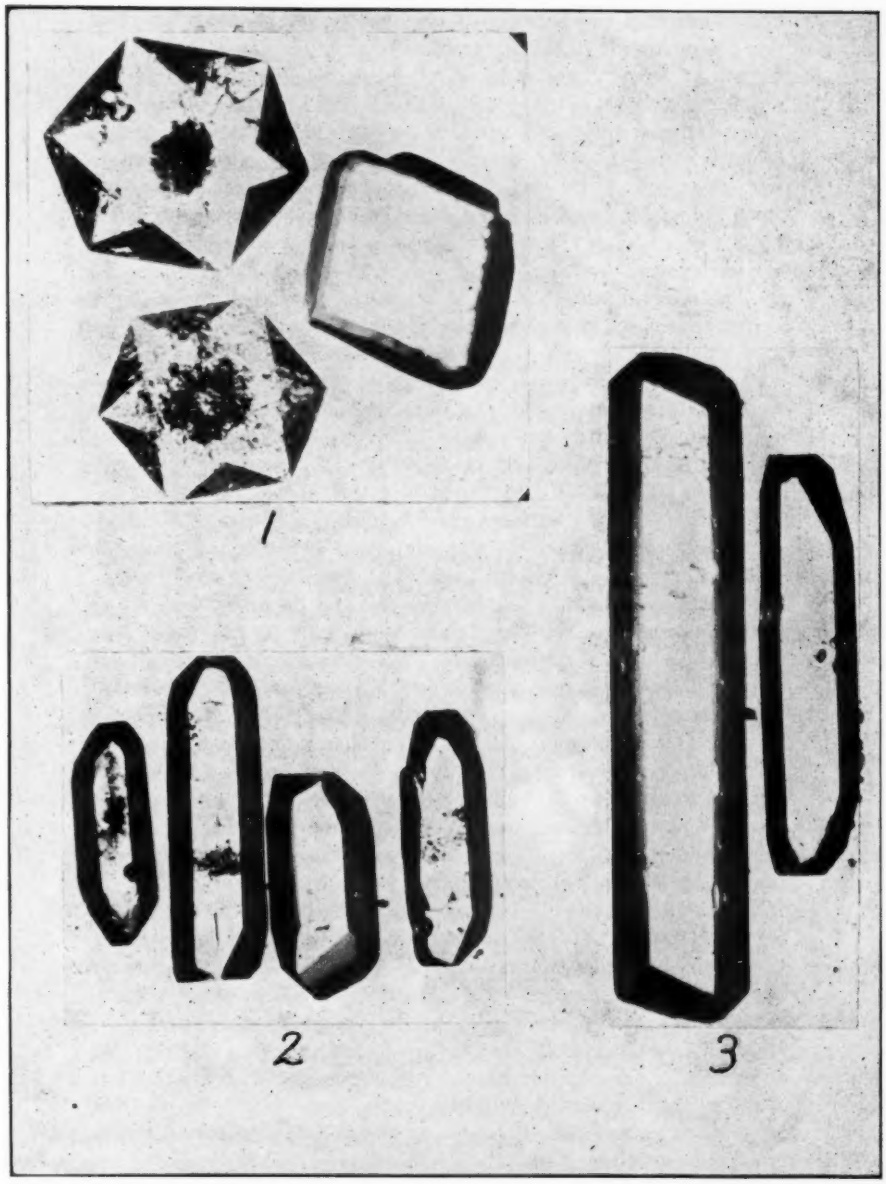

PLATE 2.—FIG. 1. Dolomite rhombs from Choctaw residue showing nuclei and development of positive and negative rhombohedrons. ×31.5.
FIGS. 2 and 3. Magnesite crystals from Choctaw residue. ×38.

crystals to such an extent as to give them a hexagonal outline. The great perfection in development of the dolomite crystals is a striking feature of most of the residues. Cleavage fragments and irregular grains are present, but they are much less common than the crystals. When transparent, or nearly so, the crystals show a definite nucleus of finely divided, white, opaque substance. Some inclusions of anhydrite and pyrite crystals and of carbonaceous matter are present. Both the magnesiodolomite and the ankerite crystals are slowly soluble in cold, 1:1 *HCl*, leaving the finely divided, white substance of the nucleus as a residue.

The ankerite differs from the magnesiodolomite in containing a higher percentage of iron, in being yellow to orange instead of white, and in having higher refractive indices. ω for the ankerite ranges from 1.72 to 1.74, and ϵ ranges from 1.52 to 1.54. The indices of the magnesiodolomite are less variable, ω equaling $1.68 \pm .005$ and ϵ equaling $1.50 \pm .005$. Other properties of the dolomite subspecies are essentially the same as those given by Winchell (1933).

Calcite ($CaCO_3$).—All of the residues contain some calcite, but this mineral is much less common than dolomite. It occurs in a variety of crystal forms, as cleavage fragments, and as irregular grains. The rhombohedral crystal habit is the most favored, but the shape is more elongate than in the case of dolomite and the crystals are not so perfectly developed. Well developed scalenohedral forms are sparingly present (Plate 4). The range in size of the calcite grains is the same as that for dolomite. The nucleus of finely divided, white substance that characterizes the dolomite crystals is generally absent in the calcite crystals. Some inclusions of black carbonaceous matter are present.

Yellow- to brown-tinted crystals are common in a few of the residues. The color is probably due to the presence of iron, although it is not present in sufficient amount to cause the refractive indices or other properties to vary appreciably with those listed for the pure mineral by Winchell (1933).

Magnesite ($MgCO_3$).—This mineral has been definitely identified from only one locality, that of the Choctaw salt dome, where it occurs in residues from two wells. Here it comprises as much as one or two per cent of some of the residues. It occurs as quite perfect, elongate hexagonal prisms modified by rhombohedrons, pyramids, and the basal pinacoid (Plate 2). The crystals are colorless, excepting an occasional one which is stained yellow, presumably by iron. Some of them contain included anhydrite grains. They vary in length from 0.1 mm. to 3.0 mm. The crystals are insoluble in cold 1:1 *HCl*. The indices of refraction (with yellow monochromatic light) are $\omega = 1.701$

$\pm .002$, ϵ' (on cleavage) $= 1.60 \pm .005$, and $\epsilon = 1.508 \pm .003$. The other properties are the same as those given by Lonsdale (1930) and Winchell (1933). According to Lonsdale (1930), magnesite crystals are quite rare, occurring in only four other localities in the United States. Schaller and Henderson (1932) report that very minute crystals are common in Permian salt of West Texas and New Mexico.

Pyrite (*and marcasite*) (FeS_2).—Crystals of pyrite, although not common, are found in nearly all of the residues. They are present in greatest number in residues of the more impure rock salt. They occur as good crystals in a wide variety of forms, as irregular grains, as inclusions in anhydrite, dolomite, and quartz crystals, or encrusting grains of other minerals. The grains vary in size from 0.05 mm. to 2.0 mm. Many of the crystals have tarnished surfaces, and some of them appear to be altering to limonite. Here and there crystal faces show pronounced etching and pitting. Some of the deep yellow crystals have been subjected to microchemical tests for copper, but the element could not be detected.

A few cockscomb aggregates of marcasite occur in two of the residues.

Quartz (SiO_2).—Like pyrite, quartz occurs in all the residues of appreciable size, although it is more rare. It is present as well developed hexagonal prisms terminated by rhombohedrons; these crystals are in many places grouped in the form of rosettes. The crystals and rosettes range in size from 0.1 mm. to about 2.0 mm. Inclusions of anhydrite cleavage fragments and of gray to black carbonaceous matter are present in some of the crystals. The quartz crystals are in places intergrown with or included in other minerals of the residue. The rosettes commonly have a nucleus of finely divided, white substance, similar to that in the dolomite crystals. Typical crystals and rosettes are illustrated in Plate 3.

Limonite ($Fe_2O_3NH_2O$).—Minute nonmagnetic crystals, apparently of isometric habit, few of them larger than 0.1 mm. in diameter, are present in virtually all of the residues. The crystals are grayish brown to brownish black and yield a powder of brownish yellow color when crushed. They are of dull to submetallic luster by reflected light and opaque under transmitted light. A few crystals are present which are much as 1.0 mm. in diameter. Microchemical tests have shown that they are only with difficulty decomposed by *aqua regia* and that they contain iron. On the strength of these tests and because of their other properties, they have been identified as limonite. Apparently these crystals are pseudomorphs after pyrite, for they occur as modified cubes, most of which have pitted or irregular faces. Some crystal

PLATE 3.—FIGS. 1 and 2. Barite crystals from Winnfield residue. ×48.5 and 33.5.
FIG. 3. Celestite crystals from Lake Washington residue. ×44.
FIG. 4. Celestite crystal from Sulphur residue. ×61.
FIG. 5. Quartz crystals and rosettes from Choctaw residue. ×37.

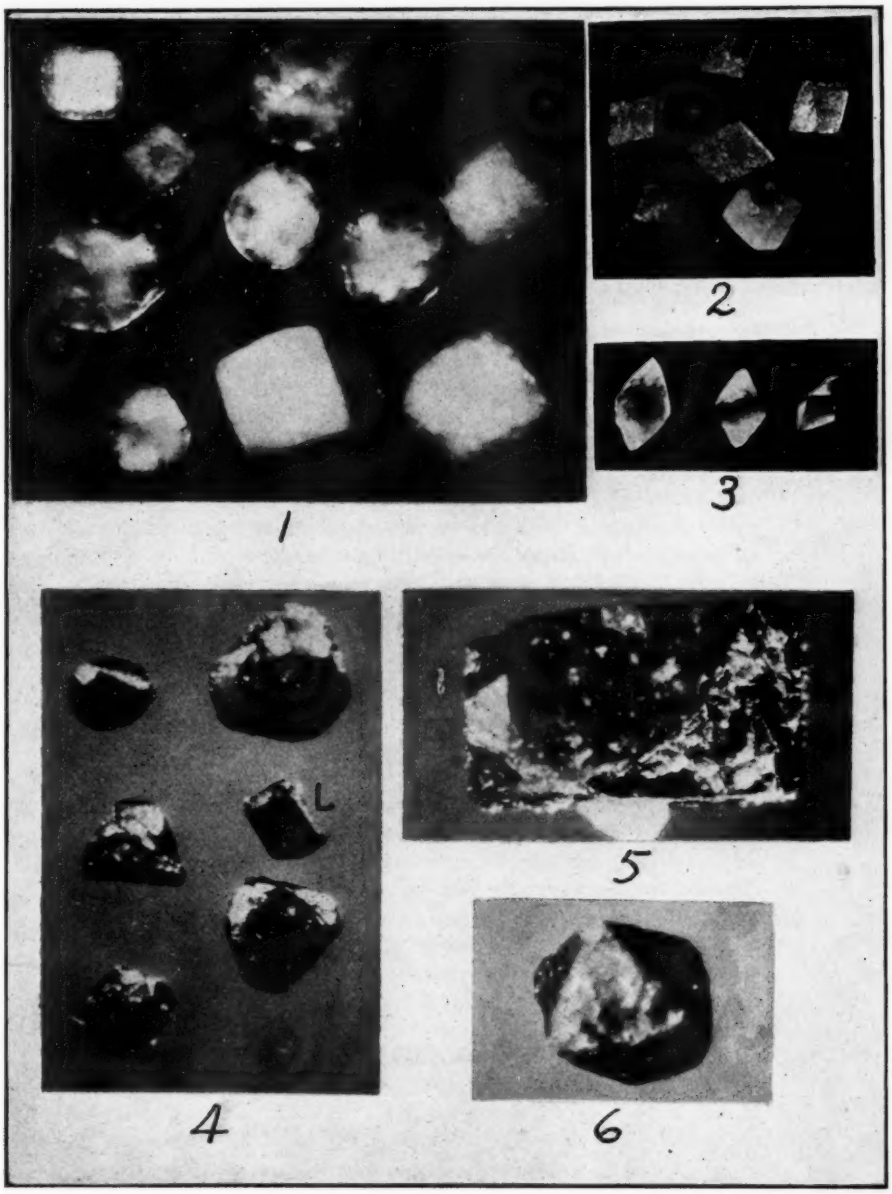

PLATE 4.—FIG. 1. Boracite crystals from Choctaw residue. ×35.
FIG. 2. Dolomite rhombs from Weeks Island residue, ×25.
FIG. 3. Calcite scalenohedrons from Avery Island residue. ×25.
FIG. 4. Five hauerite crystals and one limonite crystal (L), from Avery Island residue. ×58.
FIG. 5. Limonite from Avery Island residue. ×36.
FIG. 6. Hauerite crystal from Avery Island residue. ×35.

faces show a distinct iridescence, and a trace of manganese was detected in microchemical tests of one crystal. In places anhydrite and limonite are intergrown, and limonite crystals form the center of aggregates of small, iron-stained anhydrite grains. Some of the commoner forms of limonite are illustrated in Plate 4.

Hematite (Fe_2O_3).—Red or reddish brown hexagonal flakes of this mineral, microscopic in size, in places collect as a thin film on the water in which the salt is dissolved.

Hauerite (MnS_2).—Octahedral, or flat, pseudohexagonal, reddish brown to brownish black crystals which occur sparingly in several of the residues have been identified as the manganese sulphide, hauerite, by means of microchemical tests (Short, 1931; Curtman, 1934). This mineral also is present as a cementing material between anhydrite grains, and as irregular grains. The hauerite grains range in size from submicroscopic up to those 0.5 mm. in greatest dimension. Typical forms are illustrated in Plate 4.

Sulphur.—Irregular, transparent, yellow to greenish yellow grains of this mineral occur sparingly in several of the residues. A few of the grains have partially developed crystal faces but most of them are quite irregular in shape. Their distribution is rather sporadic, as they may be found in the rock salt from only one part of a particular salt plug.

Celestite ($SrSO_4$).—The rock salt from four localities contains well developed crystals of this mineral. The crystals from three of these localities are thin, basal tablets, elongate parallel to *a*, with orthodomes and brachydomes as a rule well developed. Those from a fourth locality, Sulphur salt dome, are larger, with diameters up to 3.0 mm., and are subspherical in shape, due to a combination of prisms, pinacoids, and possibly pyramids. These crystals are not so well formed as those of the other residues and are filled with inclusions of anhydrite, sulphur, and other minerals of the residue. Here and there cleavage fragments are present which show very good $\bar{0}01$ and distinct $\bar{1}10$ cleavage. The indices for specimens from all of the occurrences check closely with those given by Winchell (1933). The presence of the element strontium in this mineral was proved by the flame test (Curtman, 1934). Crystals of both types are illustrated in Plate 3.

Barite ($BaSO_4$).—This mineral is relatively common in the rock salt from Winnfield, and a few grains were found in that from Jefferson Island. It occurs as crystals of rectangular outline, with a length of as much as 2 mm. on a side, which are tabular parallel with $\bar{0}01$, and are modified by domes. The crystals are colorless, transparent to translucent, and contain inclusions of anhydrite grains. The refractive

indices and other properties are those for the pure mineral (Winchell, 1933). Typical crystals are shown in Plate 3.

Kaolinite.—Colorless, very thin, flexible, hexagonal plates, some of which are interpenetrating, occur sparingly in a few of the residues from Jefferson Island and Avery Island. They are all very small, less than 0.1 mm. in greatest dimension. They have been referred to kaolinite on the basis of physical and optical properties (Winchell, 1933; Larsen and Berman, 1934).

Gypsum ($CaSO_4 \cdot 2H_2O$).—Specimens of this mineral have been found only in a residue from Choctaw and one from Winnfield. Two specimens were found in the Choctaw occurrence in which sandstone and shale are present. One is a cleavage fragment of selenite about 2 cm. long with gray shale adhering to it, and the other, of microscopic size, is fibrous gypsum adhering to gray shale. These specimens had been exposed to weathering several months and it is possible that they are alteration products. Well developed, fresh crystals occur in the residue obtained from Winnfield "slab" anhydrite. However, this residue had been allowed to stand in water for about two weeks because of the compactness of the anhydrite sand, and a sample from the same slab which was allowed to remain in water only a short time did not contain gypsum. Analysis of the brine from this second sample showed the presence of nearly one per cent of soluble sulphate. It is quite possible, therefore, that the gypsum in the first sample crystallized from solution in the laboratory.

In addition to the foregoing minerals which are known to occur in more than one locality and for which occurrences are listed in Table V, a few others have been found which are confined to one locality, Choctaw.

Danburite ($CaB_2[SiO_4]_2$).—The presence of this rare calcium borosilicate, as perfect microcrystals, is one of the striking characteristics of the residue from the rock salt of the Choctaw salt plug. It occurs as colorless prisms as much as 3.0 mm. in length, in two of the residues, being fairly common in one of them. The refractive indices and other properties are the same as those given by Winchell (1933).[14] Photomicrographs of typical crystals are presented in Plate 5.

Hilgardite.—This is a new hydrous calcium borosilicate with chlorine.[15]

Boracite ($Mg_7Cl_2B_{16}O_{30}$).—Pseudocubic crystals of boracite, with

[14] C. S. Hurlbut, Jr., Harvard University, very kindly checked the optical and physical properties of this mineral.

[15] Complete data for this mineral are presented in an article, "Hilgardite, a New Mineral Species from Choctaw Salt Dome, Louisiana," by Cornelius S. Hurlbut, Jr., and Ralph E. Taylor, to be published in the *American Mineralogist* for October, 1937.

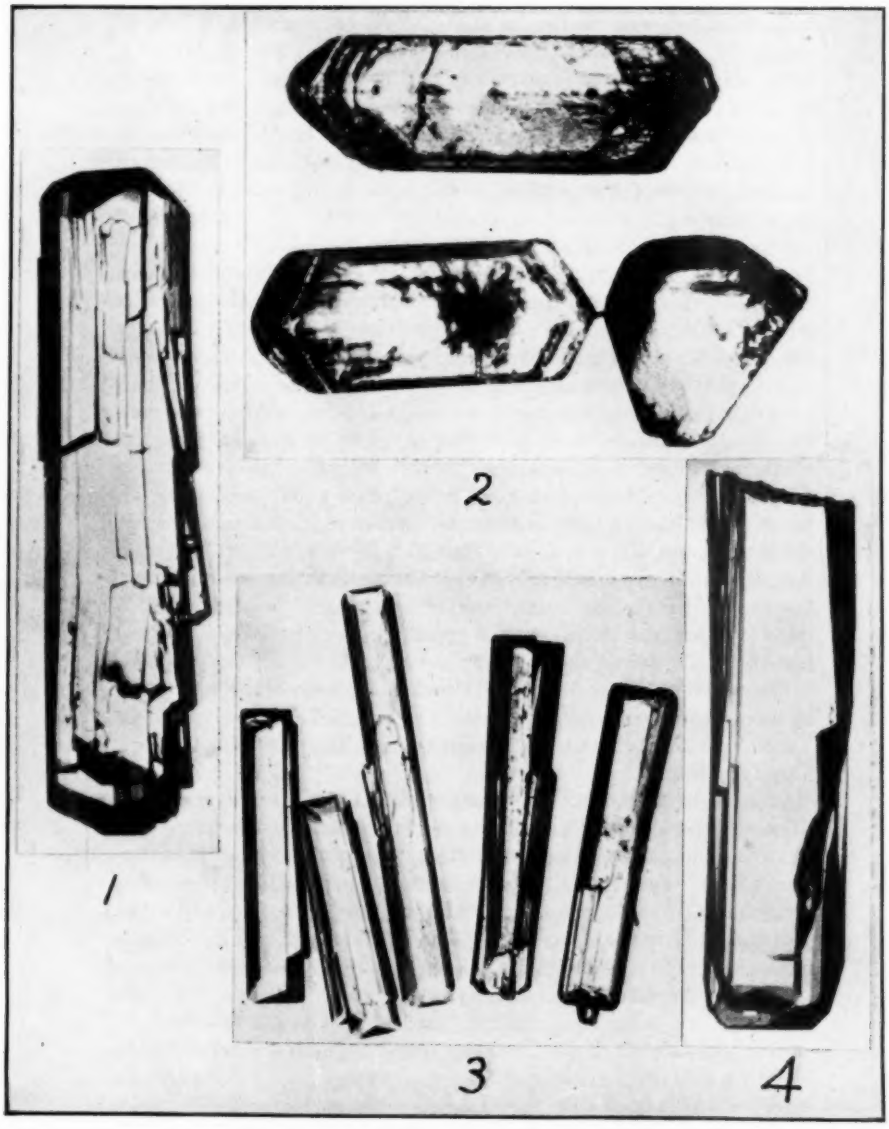

PLATE 5.—FIGS. 1, 3, and 4. Crystals of danburite from Choctaw residue. ×38.
FIG. 2. Hilgardite grains lying on good cleavage; from Choctaw residue. ×38.

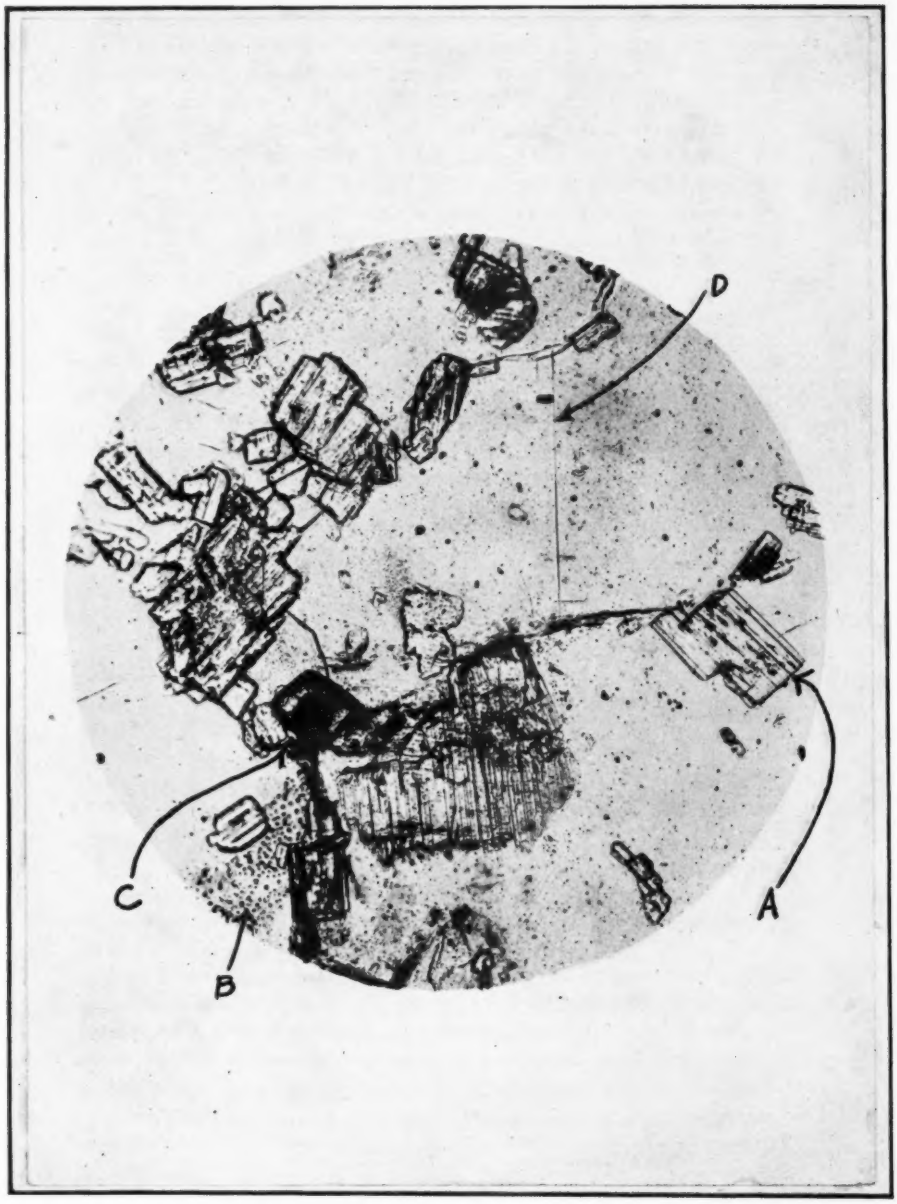

PLATE 6.—Thin section of salt from dark band in Avery Island mine, showing *A* anhydrite grains, *B* capillary tubes in halite, *C* a dolomite rhomb, and *D* halite cleavage. ×60.

internal radial structure, and varying from 0.1 to 0.5 mm. in diameter, occur sparingly in the Choctaw residue in which danburite is most common. The identity of this mineral has been established through the generous assistance of C. S. Hurlbut, Jr.[16] The physical and optical properties of the boracite are essentially the same as those given for the occurrence in the Zechstein salt of Germany (Winchell, 1933). Crystals are shown in the photomicrographs of Plate 4.

A microscopic, tabular, bluish green crystal was found in one of the residues from Jefferson Island, but its identity has not been established.

ANALYSES OF SAND INCLUSIONS

The composition of the so-called red sandstone inclusion at Avery Island has been described in some detail by Rogers ([1918]; this description was reprinted by Heald [1924]). Samples of this inclusion and of the one from Jefferson Island were subjected to detailed mechanical and petrographic analysis (Tables VI and VII). In addition,

TABLE VI

MECHANICAL ANALYSES OF SAND INCLUSIONS

Locality		*Avery Island Sand Inclusion*	*Jefferson Island Sand Inclusion*
Weight of inclusion before solution		496.5 grams	555.0 grams
Weight of sand		273.3 grams	324.5 grams
Per cent of sand in salt		55.0 per cent	58.5 per cent
Weight per cent lost in 1:1 HCl digest		4.7 per cent	3.2 per cent
	Sieve Analysis		
Retained	20	3.0	3.6
Retained	28	1.4	1.4
Retained	35	6.1	2.3
Retained	48	15.2	19.5
Retained	65	17.5	16.4
Retained	100	21.0	21.2
Retained	150	13.5	13.1
Retained	200	7.6	7.3
Retained	300	2.8	1.7
Passed	300	11.9	13.5
Total		100.0 per cent	100.0 per cent

several thin sections were prepared from specimens of each of these. A sample which is similar in appearance to these was obtained from the New Iberia salt dome.[17] It was too small to permit a complete analysis, but light and heavy separates of the whole sample were

[16] Letter of March 29, 1937.

[17] This sample was furnished by Allen Bernard, a student in the School of Geology, Louisiana State University. The only information which could be obtained about it is that it came from a Texas Company well, from within the salt plug.

subjected to a qualitative petrographic examination. The gray sand occurring in the rock salt from the Jefferson Lake Oil Company's well 245 was not subjected to detailed petrographic analysis because it is flooded with anhydrite grains; however, portions of the light and heavy separates of the fine-sand size material were examined qualitatively. Thin sections were prepared for a few of the sandstone pebbles from Choctaw.

The sands from Avery Island and Jefferson Island are very much alike, both mineralogically and physically. They are both essentially poorly sorted sands cemented by rock salt and contain small dolomite-cemented areas. The larger grains are well rounded, the average for the sands being from subangular to subrounded. The light separates of each are made up almost wholly of quartz grains, characterized by tourmaline and rutile inclusions, and the heavy separates are composed of an assemblage of resistant minerals. Brine collected during solution of these inclusions gives a strongly positive potash test. The red color of the inclusions from the mines at Avery Island and Jefferson Island is due to the coating of iron-oxide stain on the quartz grains, and to the hematite flakes.

Brine from solution of the New Iberia inclusion also gives a positive test for potash, but that from well 245, Jefferson Island salt dome, gave a negative reaction. However, the sand from well 245 seems to resemble the Avery Island and Jefferson Island red sands more closely in mineral composition than does the New Iberia sand. Aside from the absence of hematite and the flooding of anhydrite grains, the well 245 sample is the same as these other sands. The New Iberia red sand differs from the others in having a higher percentage of feldspars and an appreciable amount of volcanic glass in the light separate, and having a less varied assemblage of tourmalines in the heavy separate.

The sandstone pebbles from Choctaw salt dome are light gray, loosely compacted, argillaceous sandstone. A few of the pebbles are stained by iron oxide, and some of the smaller ones have siliceous cementing material. Quartz is the chief constituent and it occurs as poorly sorted grains from silt size to coarse sand size. The larger quartz grains are fairly well rounded. The clay in the argillaceous sandstone is altering to sericite. Heavy minerals are rare and are chiefly zircon, tourmaline, and leucoxene. Gray to black siltstone and shale pebbles are also present in the Choctaw residue. Crystals of calcite, dolomite, pyrite, and anhydrite occur as small veins and vugs in some of the pebbles, or as encrustations. From what is known of the sandstone inclusions at the salt mines, there seems little doubt that

TABLE VII

PETROGRAPHIC ANALYSES OF SAND INCLUSIONS

	Avery Island				*Jefferson Island*			
	Whole Sample	*150-Mesh*	*200-Mesh*	*300-Mesh*	*Whole Sample*	*150-Mesh*	*200-Mesh*	*300-Mesh*
Bromoform separation: weight per cent heavy separate	0.36 per cent	0.40	1.12	2.23	0.23	0.70	1.25	4.20
Weight per cent magnetite in heavy separate	16.6	16.1	11.9	9.4	12.3	9.1	7.0	9.5
Frequency percentage heavy minerals (less magnetite)								
Ilmenite	10 per cent	4 per cent	6 per cent	5 per cent	4 per cent	2 per cent	4 per cent	11 per cent
Leucoxene	42	61	62	50	51	57	58	21
Limonite and hematite	33	7	4	5	10	5	9	3
Pyrite	R*	P*	P	P	—	—	—	R
Rock grains	1	1	P	P	—	5	P	1
Zircon colorless	5	5	12	26	16	3	13	56
Zircon purple	R	R	P	P	P	1	P	2
Tourmaline pale yellow to brown or greenish brown	6	13	9	6	9	19	13	1
Tourmaline yellow-green to brown or black	2	7	4	1	8	8	2	P
Tourmaline pale greenish yellow to blue	R	1	P	P	P	P	R	R

* *R* indicates that only one or two grains of the mineral were found; *P* indicates that more grains are present than in the case of *R*, but less than one per cent.

Rutile	P	P	1	5	P	R	P	4
Anhydrite	P	1	P	P	P	P	—	—
Dolomite	P	—	P	P	—	P	—	—
Titanite	P	—	—	R	R	R	—	R
Hornblende	R	P	P	R	R	—	—	—
Muscovite	—	R	R	R	R	R	R	R
Epidote	R	—	—	R	R	—	—	—
Apatite	—	—	—	R	R	—	—	—
Chlorite	P	—	P	—	—	—	—	—
Actinolite	—	—	—	R	—	—	—	—
Garnet	—	—	—	—	—	R	R	—
Kyanite	—	—	—	—	—	—	R	—
Brookite	—	—	—	—	—	—	—	R
Frequency percentage light minerals	*100-Mesh*	*150-Mesh*	*200-Mesh*		*100-Mesh*	*150-Mesh*	*200-Mesh*	
Quartz	97 per cent	98 per cent	94 per cent		86 per cent	87 per cent	81 per cent	
Chert	1	2	4		12	12	16	
Clay grains	1	P	P		1	P	1	
Weathered feldspar	—	—	—		—	P	—	
Plagioclase feldspar	P	P	1		P	P	1	
Muscovite	—	—	R		—	—	—	
Glauconite	—	—	—		—	R	—	
Roundness classification (by estimation)	*Sub-rounded*	*Sub-angular*	*Sub-angular*		*Sub-rounded*	*Sub-angular*	*Sub-angular*	

these pebbles were derived from beds or lenses of detrital materials that were broken up during the production of brine.

Rogers (1918) reported the inclusion from Avery Island as being a siliceous-cemented sandstone, and thought of it as having been "plucked" or picked up from adjacent strata during intrusion of the rock salt. However, the inclusions studied by the writer have rock salt or salt clay as the cementing material, excepting in the case of certain of those from Choctaw. This suggests that most of these inclusions could have been lenses in the original bedded salt deposits. The presence of varying amounts of detrital quartz grains widely disseminated through the rock salt of many of the salt plugs, is evidence in favor of this explanation.

Sufficient evidence is not available to warrant definite conclusions regarding correlation of the sand inclusions with other Gulf Coast sediments. The red color of some of the sand inclusions is distinctive, as no sands of similar appearance are known from the Gulf Coast Tertiary. The absence of aluminium silicates, staurolite in particular, and possibly of garnet, is another possible diagnostic feature of these sands by which they can be differentiated from the few Gulf Coast sands which have been studied petrographically. It is possible that after further petrographic studies of Gulf Coast sediments and of sand inclusions have been carried out, a correlation can be made.

CHEMICAL COMPOSITION OF GULF COAST ROCK SALT

The analyses presented in Table VIII give only a very general idea of the chemical composition of the rock salt. They afford sufficient information, however, to show that chemically this rock salt is very like that of other regions. The analyses of Avery Island salt, and the analysis of salt from a "wet spot" at Jefferson Island, indicate the presence of soluble $CaSO_4$, as well as of the relatively insoluble anhydrite. In every instance where the brines which result from the solution of salt specimens were analyzed they were found to contain $CaSO_4$ in solution, and where quantitative analyses were made, more was found to be present than is soluble in pure H_2O. It seems quite probable that some of the anhydrite was taken into solution when the salt specimens were being dissolved. The apparent solution of anhydrite and the precipitation of gypsum in a sample of "slab" anhydrite from Winnfield has been noted under the discussion of gypsum.

The "soft" salt from Winnfield which contains barite was also found to contain the element barium. Strontium was not detected in any of the samples, including those in which celestite occurs.

The presence of appreciable amounts of iron in the natural brines

TABLE VIII

CHEMICAL ANALYSES OF ROCK SALT

Locality		*Avery Island Salt Dome (Avery Rock Salt Mining Company)*			*Old Hackberry Salt Dome (Mathieson Alkali Works)*	*Jefferson Island Salt Dome (Jefferson Island Salt Mining Company)*			*Weeks Island Salt Dome (Myles Salt Company)*			*Winnfield Salt Dome (Carey Salt Company)*		*Choctaw Salt Dome (Solvay Process Company)*
		"No. 1" Rock Salt	*"Coarse" Rock Salt*	*"Granular" Rock Salt*	*Rock Salt Well No. 1*	*"C" Rock Salt*	*"C" Rock Salt*	*Rock Salt from "Wet Spot" Mine*	*"Mine Fine" Rock Salt*	*"A" Rock Salt*	*"H" Rock Salt*	*No. 1 Rock Salt*	*Untreated Table Salt*	*Composite Sample from Cores*
		Per Cent	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*
	$Na\ Cl$	99.035	99.008	99.137	95.720	98.950	98.730	98.820	97.92	99.10	98.923	96.88	98.83	97.710
	$Ca\ SO_4$	0.227	0.223	0.166	3.950	1.032	1.192	1.129	1.93	0.81	0.941	1.08	0.31	2.140
	$Ca\ Cl_2$	0.024	0.020	0.026	0.140			0.040				0.46	0.07	None
	$Ca\ CO_3$	—	—	—	None	—	0.053					Trace	Trace	
	$Si\ O_2$	—	—	—	0.030	0.004	0.014	0.001				Trace		0.064
	$Mg\ Cl_2$	0.019	0.019	0.017	0.008	0.006	0.006	0.006					0.03	None
	$Mg\ SO_4$	None	None	None	—				0.02		0.003			0.036
	$Na_2\ SO_4$	None	None	None	—									0.046
	$Fe_2\ O_3$	None	None	None	0.012			(“Iron” present)	0.05	0.01	0.083	Trace	Trace	0.005
	$Al_2\ O_3$													0.004
	K Cl				None									(Low *K* test on spectrograph)
	Ba				None									
	Sr				None									
	Br				Minute trace									
	H_2O	0.009	0.012	0.012	—				0.04	0.03	0.004			None
Organic matter		—	—	—	None									
Water insolubles		0.686	0.718	0.642	—			0.032	0.032					
Acid insolubles						0.004	0.014							
Total Per Cent		100.000	100.000	100.000	99.860	99.996	100.019	100.028	99.99	99.95	99.954	98.42	99.24	100.005

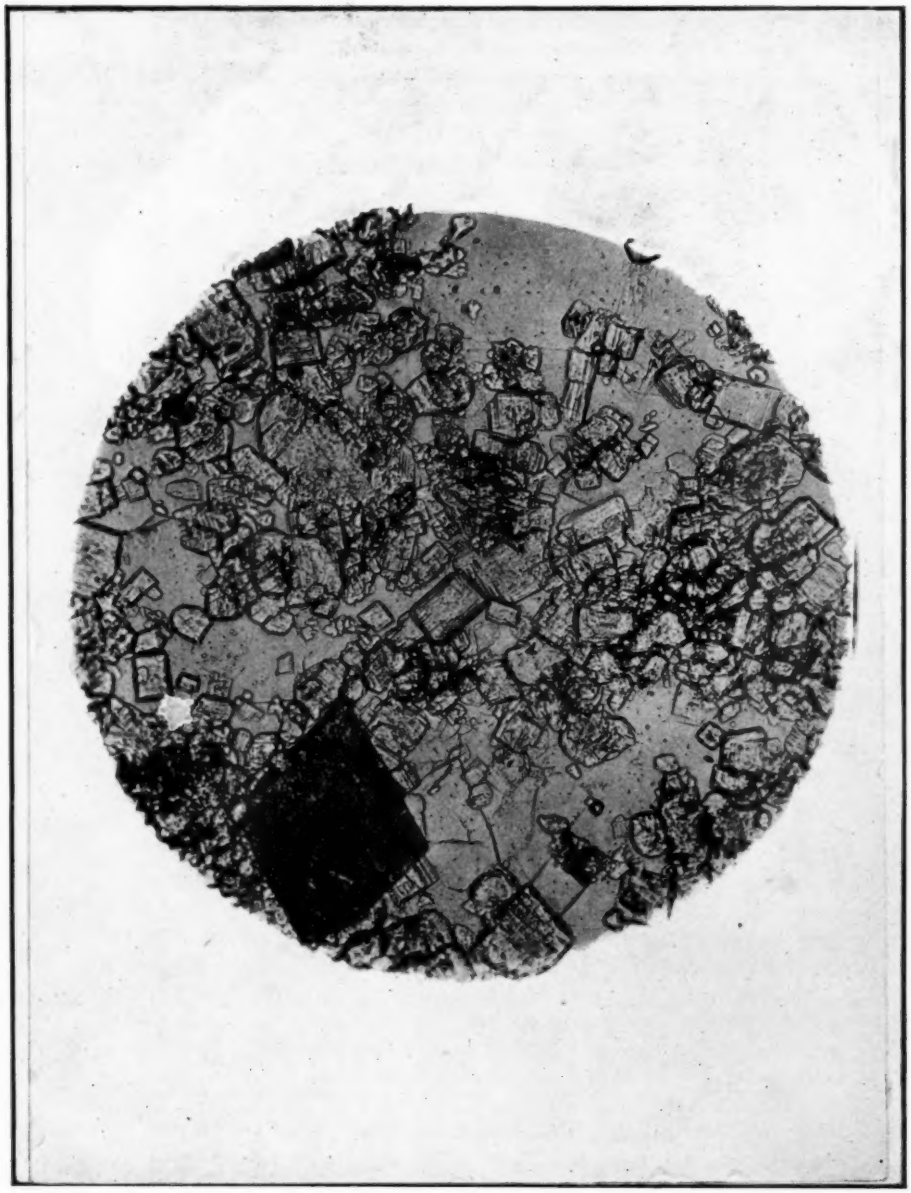

PLATE 7.—Thin section of rock salt from Weeks Island mine (sample 4, Table IV), showing crushed condition of anhydrite grains and large dolomite rhomb. ×70.

PLATE 8.—Thin section of red sand inclusion from Avery Island mine. ×60.

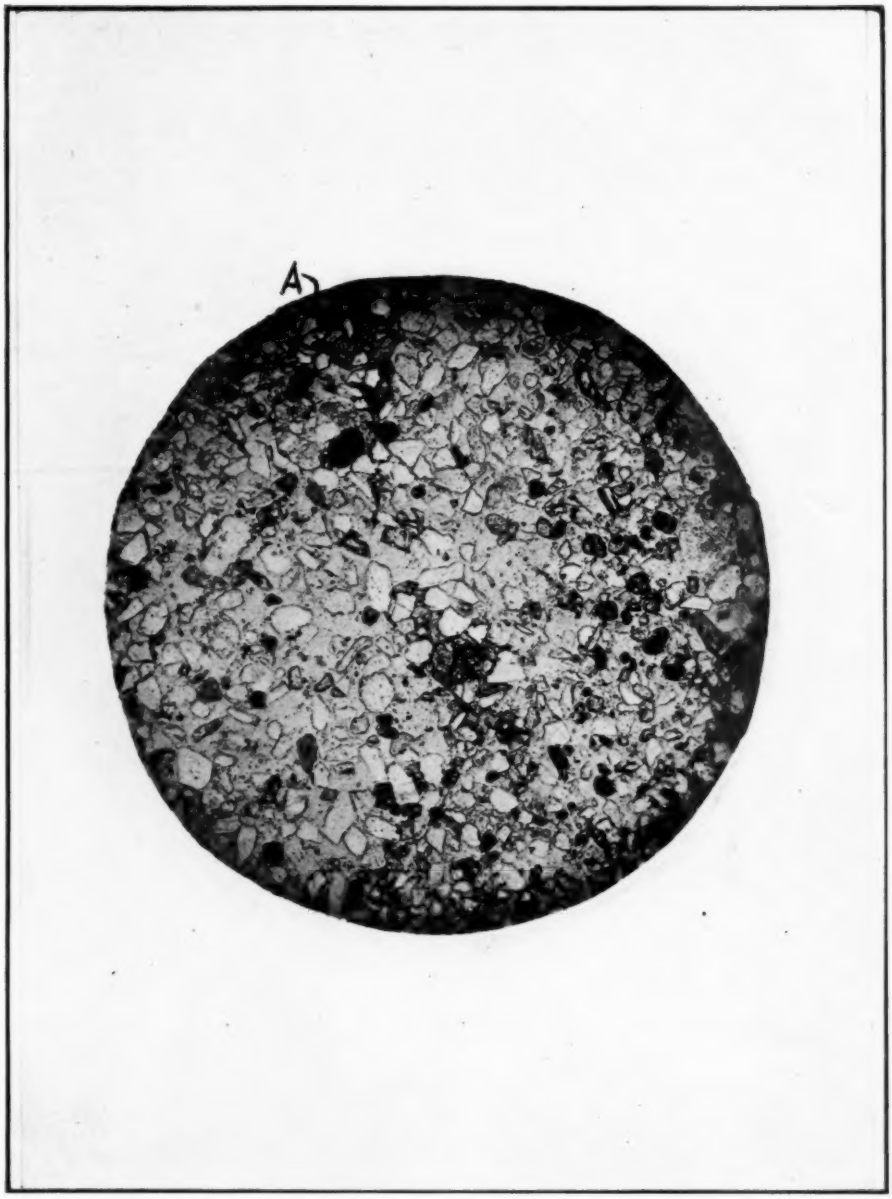

PLATE 9.—Thin section of sand inclusion from Jefferson Island mine; areas marked *A* are calcite or dolomite cemented. ×20.

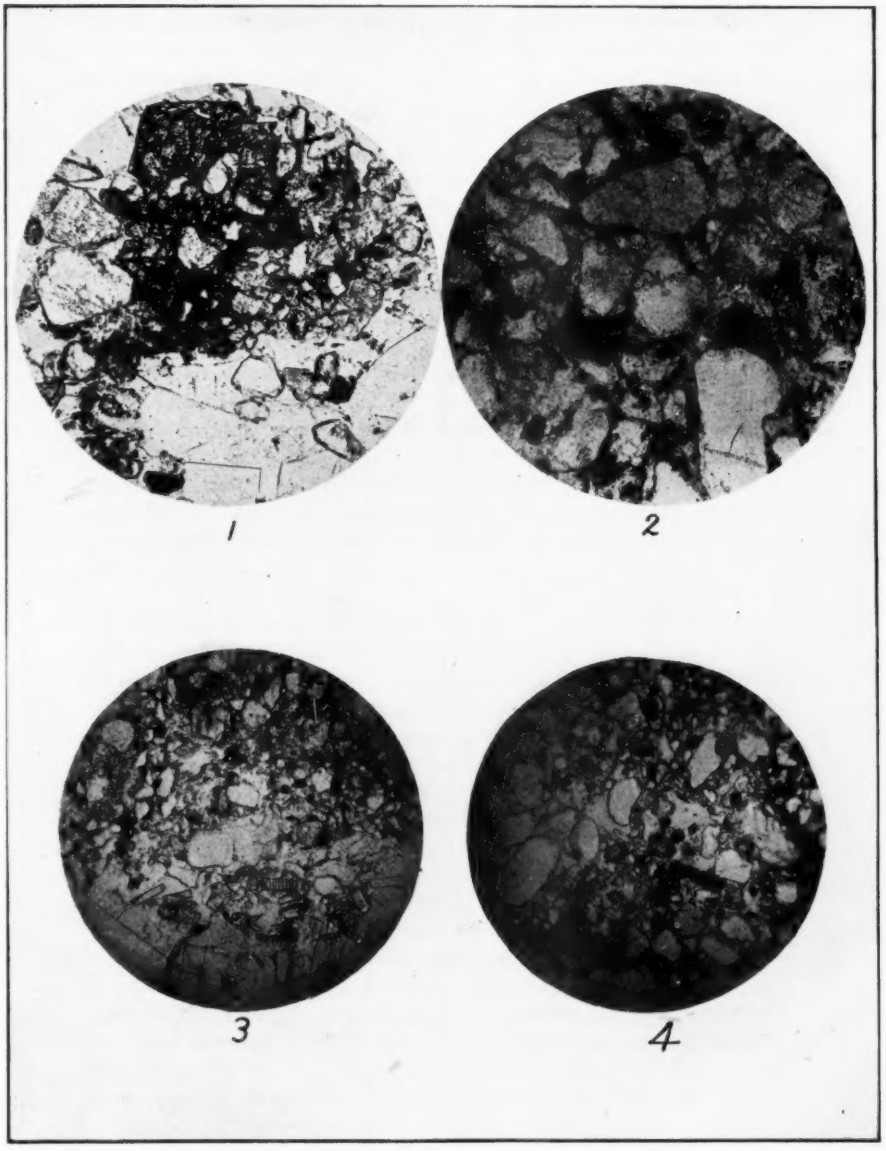

PLATE 10.—FIG. 1. Thin section of sand inclusion from Jefferson Island mine showing calcite or dolomite cemented area. ×25.

FIG. 2. Thin section of sand inclusion from Weeks Island mine. ×38.

FIG. 3. Thin section of sand inclusion from Jefferson Island mine showing contact with halite containing anhydrite crystals (*A*). ×16.

FIG. 4. Thin section of sand inclusion from Jefferson Island mine. ×16.

that occur in the mines at Winnfield and Jefferson Island has already been referred to. Segura[18] reports as follows on brine from a wet spot at Jefferson Island (see Table VIII for an analysis of the salt).

> Inasmuch as semi-quantitative analysis of liquid drawn from this spot showed the main impurities to be Calcium Chloride, Magnesium Chloride, Iron and heavy traces of Calcium Sulphate, we are led to believe that the liquid is the "mother liquor" from which the salt was crystallized. This is more or less confirmed by the difference in their respective crystallization values.

SUMMARY AND CONCLUSIONS

Although data are available from only about 30 of a total of 134 localities, it is evident that the rock salt of the Gulf Coast salt plugs is fully as complex in character as that of other regions. The salt plugs contain a complex assemblage of water-insoluble minerals and rock inclusions, soluble salts other than halite, gases of different composition, and oil. An average for the total amount of water insolubles present in the rock salt from Gulf Coast salt plugs is difficult to give because of the great variability of different deposits. Hanna's figure of 5–10 per cent (1934) does not seem too high when all of the contributing factors are taken into consideration, and this figure is similar to those given by Bretnütz, Lachmann, and others for the German salt plugs.

Comparisons indicate that the mineral assemblage of water-insoluble residues of the Gulf Coast rock salt is different from that of the Silurian and Permian deposits of North America. The striking similarity of all the Gulf Coast residues suggests that further comparisons might afford clues to the age of the salt. Data on the residue in the rock salt of Lower Cretaceous age at the Chittim locality, Maverick County, Texas, are particularly desirable. Although it might not be possible to establish a definite correlation on this basis, no line of evidence which might aid in the solution of this difficult problem should be overlooked.

The dominant feature of the water-insoluble residues is the high percentage of anhydrite grains. In addition to anhydrite, perfect rhombohedral crystals of dolomite containing distinctive nuclei, crystals, and nuclei-bearing rosettes of quartz, and pyrite crystals, typify the water-insoluble residues of the rock salt of the Gulf Coast salt plugs. All of the residues appear to contain these minerals, and some have in addition distinctive minerals which set them apart from the others. The sands of the inclusions differ sufficiently from sands of the Gulf Coast Tertiary to permit them to be classified as distinctive

[18] Personal communication from M. A. Segura, chemist.

It seems reasonable to conclude, therefore, that if this same assemblage of water-insoluble minerals which characterizes the salt plugs occurs in the associated cap rock, definite evidence indicating the formation of cap rock through accumulation of water-insolubles in the salt will have been established.

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USE OF MECHANICAL SAND ANALYSES FOR CORRELATION PURPOSES[1]

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ABSTRACT

In place of the usual methods of recording the data obtained by mechanical sand analyses and routine paleontological data, a new method is described which has been proved accurate, flexible, and adaptable to changing sedimentary conditions.

Mechanical shaking was used to obtain the screen analyses rather than hand shaking, as it was faster and much more thorough. Early in the course of study, anomalies in distribution of cuts throughout the screen stack led to the conclusion that the screens were not correctly designed to yield accurate data. The screens used were examined and from the fifteen screens available in the set, a suite of eight screens was used which avoided the objections raised by using the original set of screens.

The data derived from the screen analyses plus paleontological information secured from examination of the samples were plotted on transparent, punched, index charts. With the use of these cards, correlations were made between two producing horizons on the flank of one of the Gulf Coast salt domes, which gave, in addition to the relationship of the two sand zones, an accurate contour map of that section of the dome.

More detailed study of the upper zone permitted the tracing of the individual members across its areal extent, which showed the detailed information of the deposition cycle within the sand body. From this information, and supplemented by further data derived from the studies of the sediments on the same dome, the geological history of the Lower Miocene was established.

INTRODUCTION

The use of mechanical analyses of sand samples in the study of geological problems has been discontinued. The reason, in part at least, has been that the method has not justified the time and detail necessary to make the analyses, in that the correlations resulting from the data obtained have not been conclusive enough, and may even lead to faulty interpretation.

The paleontological analysis of well samples, limited to the determination of the first occurrence of characteristic species, is commonly used in the Gulf Coast area. Very little use is made of the vast amount of information available with regard to the other foraminifera or the larger shells, their presence, absence, or relative abundance, because such analyses show great variations even within the same core, and are not conclusive or sensitive enough to be at all final and exact.

Field observations show that within a limited area, under similar conditions of deposition, many of the sand and paleontological analyses of samples are very similar in character. The failure of the analyti-

[1] Manuscript received, May 24, 1937.

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cal method of correlation of well samples must therefore be traced not to the lack of evidence but rather to the fact that the evidence, as used, is insufficient, and the samples as taken in two wells do not correspond exactly in position with regard to the correlating horizons.

Several attempts were made to combine the data obtained from sand analyses with the complete paleontological record of the sample, showing all of the species, together with their relative abundance. In general, the tabulations made were clumsy, obscure, and rigid, with the result that out of a vast amount of information very few correlations could be made, the correlations being, therefore, negative and not conclusive.

This paper is a summary of the results obtained by the use of an improved method of recording sand and paleontological analyses of samples by the use of transparent, punched, index charts. The results obtained have been found to be conclusive, and sufficiently accurate to allow detailed studies to be made, while, at the same time, the method presented great flexibility and adaptability to changing conditions in the problem.

It is doubtful whether or not much of the material included in this paper would have been discovered without the use of this method.

DESCRIPTION OF METHOD

PREPARATION OF SAMPLE

The samples used in this study were taken from well cores from a piercement type salt dome in southeastern Texas. The minimum weight of sample used for analysis was 2 grams; the maximum weight was 20 grams. In all cases, as large a sample as possible was used, the average weight being between 10 and 20 grams.

The samples were digested in a flask with dilute hydrochloric acid until effervescence had ceased. This process served the dual purpose of removing carbonates (micro-paleontological determinations had been made before using the sample for screen analysis) and reducing the sample to discrete grains. The samples were then thoroughly washed to remove all traces of acid, decanted after allowing the sediment to settle for 2 minutes to prevent loss of the finer grains, and carefully dried in an electric oven.

DESCRIPTION OF SHAKER

The shaker (Fig. 1) consists of a motor, a flywheel with an attached eccentric, and a vibrating board on which the stack of screens rests.

The source of power was a 110-volt motor developing 1,750 R.P.M. The power was transmitted to the flywheel by a circular belt.

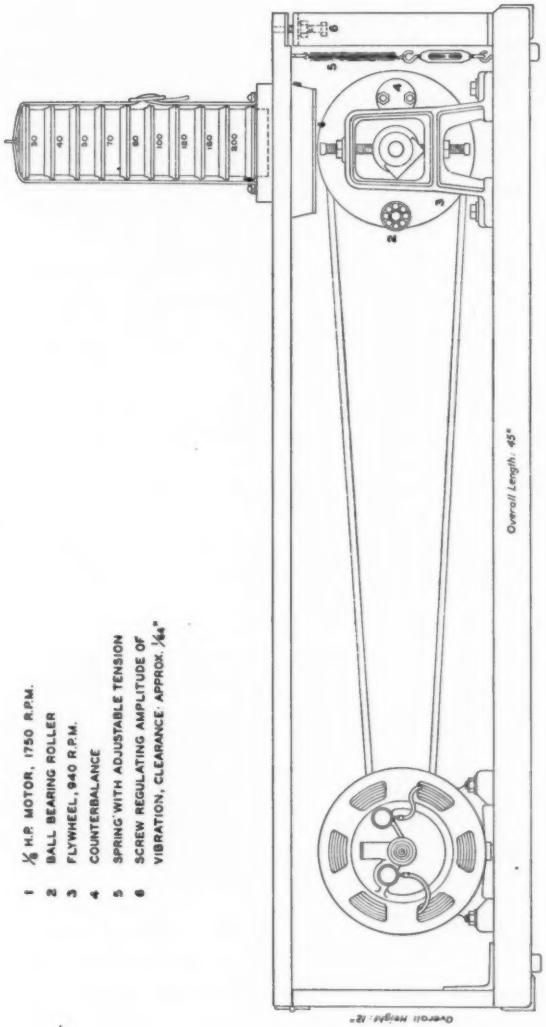
1 ⅛ H.P. MOTOR, 1750 R.P.M.
2 BALL BEARING ROLLER
3 FLYWHEEL, 940 R.P.M.
4 COUNTERBALANCE
5 SPRING WITH ADJUSTABLE TENSION
6 SCREW REGULATING AMPLITUDE OF VIBRATION, CLEARANCE APPROX. 1/64"
Overall Length 45"
Overall Height 12"

FIG. No. 1

MECHANICAL SAND SHAKER

0 1' 2' 3' 4' 5' 6'
Graphic Scale

FIG. 1

The vibratory board is hinged at the end nearest to the motor, while at the opposite end it rests on an adjusting screw. A steel plate is fastened at the point of contact with the adjusting screw to prevent wear and to allow a more accurate adjustment to be made.

The vibratory movement is transmitted from the flywheel to the vibratory board by means of an eccentrically located ball-bearing which meets a steel plate at the base of the vibratory board with a wipe contact. Very little wear is caused by this mechanism, which was found to be satisfactory in all respects.

Immediately above the point of contact of the eccentric with the vibrating board the stack of screens was placed, resting in a depression on top of the vibrating board, and held in place by an elastic webbing going over the top of the stack of screens.

Two springs hold the vibrating board against the adjusting screw with any desired amount of tension. The vibrating board is not in contact with the flywheel, and is lifted against the tension of the springs only upon the contact with the eccentric bearing. The amount of lift is less than 1/64 inch.

Because of the frequency of impact (940 times per minute) the amplitude of movement of the sand particles within the screen stack must be small enough to permit the smallest grains to fall back on the screen between periods of upward movement if thorough screening action is to be obtained.

Compared with hand shaking as done before the shaker was designed, mechanical shaking is much more satisfactory and reliable.

SCREENING PROCESS

The screen stack was vibrated for thirty minutes for each sample. It was found that after vibrating for five minutes most of the coarser material had been well separated, but microscopic examination of the finer cuts showed that some very fine silt still adhered to the grains ranging in size between 100- and 200-mesh. The pan at the base of the stack was examined at 5-minute intervals for 1 hour during the experimental stages of the work and it was noted that after 25 minutes had elapsed less than 1 per cent of the total weight of the cut on the 200-mesh screen came through during the remaining 35 minutes of shaking.

Inasmuch as microscopic examination of the coarser grains showed no fresh fractures either before or after shaking, it is not likely that breakage of grains resulted from the long period of vibration and it is certain that a complete separation of the sample into various sized grades resulted from the process.

SCREEN DATA

A stack of fifteen sieves 3 inches in diameter was purchased from a reliable manufacturer of laboratory equipment. The sieves were furnished with the wire specifications listed in columns 2 and 3 of Table II.

The differences in size of the interwire openings of two consecutive screens as calculated from these data are shown in Table I.

TABLE I

Screen Cut	Difference in Size of Opening (Inches)	Sample A		Sample B		Sample C		Sample D	
		Weight (Grams)	Weight Per Cent	Weight (Grams)	Weight Per Cent	Weight (Grams)	Weight Per Cent	Weight (Grams)	Weight Per Cent
Mesh									
20– 30	.0137	.193	1.78	.051	.66	.613	3.10	.151	1.97
30– 40	.0053	.607	5.60	.071	.92	.514	2.60	.171	2.23
40– 50	.0040	1.301	11.99	.579	7.49	.666	3.37	.272	3.55
50– 60	.0023	1.164	10.73	.995	12.86	.681	3.45	.310	4.05
60– 70	.0014	.132	1.22	.143	1.85	.099	.50	.059	.76
70– 80	.0005	2.514	23.18	2.627	33.97	5.522	27.96	1.650	21.53
80– 90	.0007	1.082	9.97	.993	12.84	2.293	12.12	1.158	15.11
90–100	.0006	.432	3.98	.084	1.09	.772	3.91	.200	2.61
100–120	.0009	.518	4.77	1.136	14.70	1.491	7.55	1.812	23.65
120–140	.0004	1.120	10.33	.624	8.07	3.469	17.57	1.070	13.96
140–200	.0013	1.784	16.45	.431	5.57	3.528	17.84	.810	10.57
200–		2.120		.150		1.292		.422	
Totals		10.847	100.00	7.734	100.02	19.748	100.00	7.663	99.99

TABLE II

Gauge	Diameter of Wire (Inches)	Space Between Wires (Inches)	Size of Space and Wire (*a*)	Ratio of Space to Wire (*b*)	Computed Size	
					Wire (*c*)	Space (*d*)
30	.0130	.0203	.0333	2.20	.0104	.02290
40	.0100	.0150	.0250	1.50	.0100	.01500
50	.0090	.0110	.0200	1.30	.0087	.01130
60	.0080	.0087	.0167	1.15	.0078	.00890
70	.0070	.0073	.0143	1.50	.0057	.00860
80	.0057	.0068	.0125	1.20	.0057	.00860
90	.0050	.0061	.0111	1.30	.0048	.00630
100	.0045	.0055	.0100	1.50	.0040	.00600
120	.0037	.0046	.0083	1.50	.00332	.00498
140	.0029	.0042	.00714	1.50	.00285	.00429
160	.0025	.0037	.00625	1.47	.00253	.00372
180	.0023	.0033	.00556	1.60	.00214	.00342
200	.0021	.0029	.00500	1.38	.00210	.00290

On the assumption that, in general, the greater the difference in size of opening between two consecutive screens, the larger the sand cut retained, a comparison is offered between the size of cuts as actually measured from four separate samples and the differences in interwire size of consecutive screens.

It will be noted from Table I and Figure 2 that the 60/70 cuts and the 90/100 cuts are very small compared with the oth csruts, whereas the 70/80 and the 100/120 cuts are too perstentle yĺaeirg to

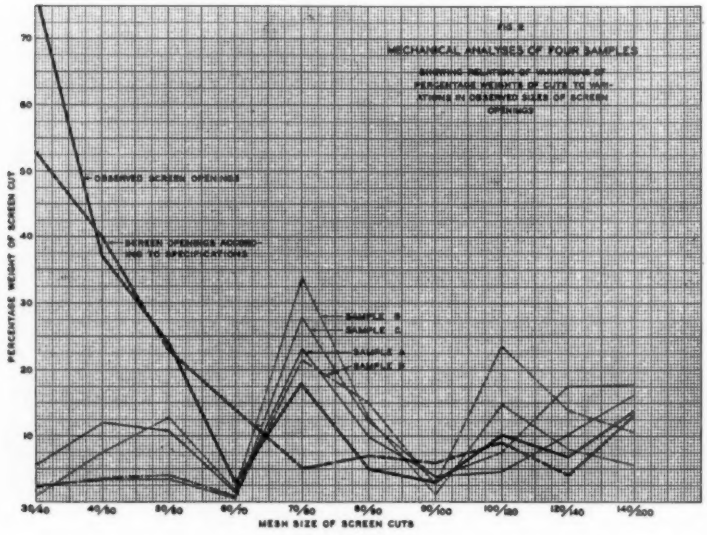

FIG. 2

be attributed to the characteristic sand sorting of the four samples and seemingly should be attributed to the variation in screen size. The difference in size opening, as calculated from the wire specifications furnished by the manufacturer, failed to show any reason for the noted variation of the percentage size of the cuts. Thereupon a calibration of the wires was made to ascertain the correctness of the specifications.

The counting of the wires checked exactly with the corresponding mesh size. There were no irregularities in the weaving of the mesh, and the wires were smooth. Because the direct measurement of the diameter of the wire was difficult, the diameters were calculated by measuring the ratio of space to wire. Table II gives the diameters of

the wires and the sizes of the intervening spaces as measured and also as per specification.

The first column in Table II gives the gauge size or number of wires per inch. The fourth column gives the size of one space and one wire (a) which value is obtained by dividing one inch by the number of wires per inch or mesh size. The fifth column gives the observed ratio (b) of the computed size of the interwire space (d) to the diameter of the wire (c). The sixth column gives the computed diameter of the wire (c). The seventh column gives the computed interwire space (d). The second and third columns, as already noted, give the manufacturer's specifications. The value of (c) and (d) are calculated from the following relationship.

$$c=\frac{a}{1+b}$$

$$d=a-c$$

The table shows that the difference in interwire space between the 60- and 70-mesh screens is 0.0003 inch, whereas the difference between the 50- and 60-mesh screens is 0.0024 inch and the difference between the 70- and 80-mesh screens is 0.0018 inch. The small difference in interwire size between the 60- and 70-mesh screens explains why all of the four samples analyzed and listed in Table I show a very small percentage of the 60/70 cut. According to the specifications furnished by the manufacturer, the difference in interwire size of the 60- and 70-mesh screens should have been 0.0014 inch, which would have been larger than the difference of 0.0005 inch specified for the 70/80-mesh screens. The analyses of the samples and the measuring of the wire showed that the 60/70 cut should be small due to the small difference between the interwire sizes of the respective screens, whereas the 70/80-mesh cut should be large because of the greater difference between interwire sizes of the screens.

The wire measurements calculated and shown in Table II are not as accurate as might be desired, because of the lack of proper measuring equipment, but their approximation is closer to the actual size of the wires than the sizes given in the letter of specifications supplied by the manufacturer. The same screens made by the same manufacturer are used by several of the larger oil companies and it is recommended that all screens be calibrated before being put into service.

Figure 3 shows a plot of the interwire screen size for the different screens and the grouping of these screens in order to obtain, as nearly

as possible, even sand cuts. Though the grouping of screens as selected in the following lists is not perfect, it was considered the best possible under the circumstances and proved by actual tests to be satisfactory. As wire specifications may vary from screen to screen

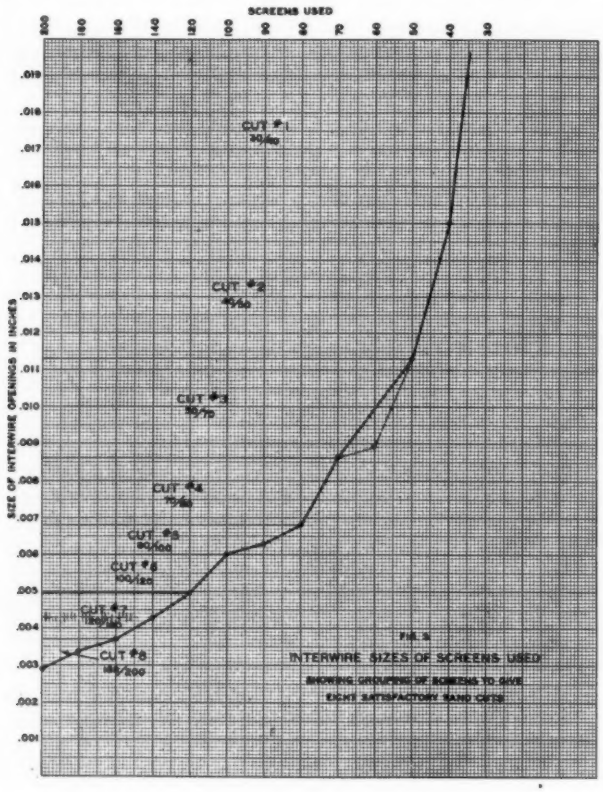

FIG. 3

and from manufacturer to manufacturer, this grouping should not be used without checking the diameters of the wires.

The following cuts were used for purposes of correlation: 30/40, 40/50, 50/70, 70/80, 80/100, 100/120, 120/160, and 160/200.

Sand retained on the 30-mesh screen and that passing through the 200-mesh was saved but not weighed and was not included in the percentage distribution of cuts.

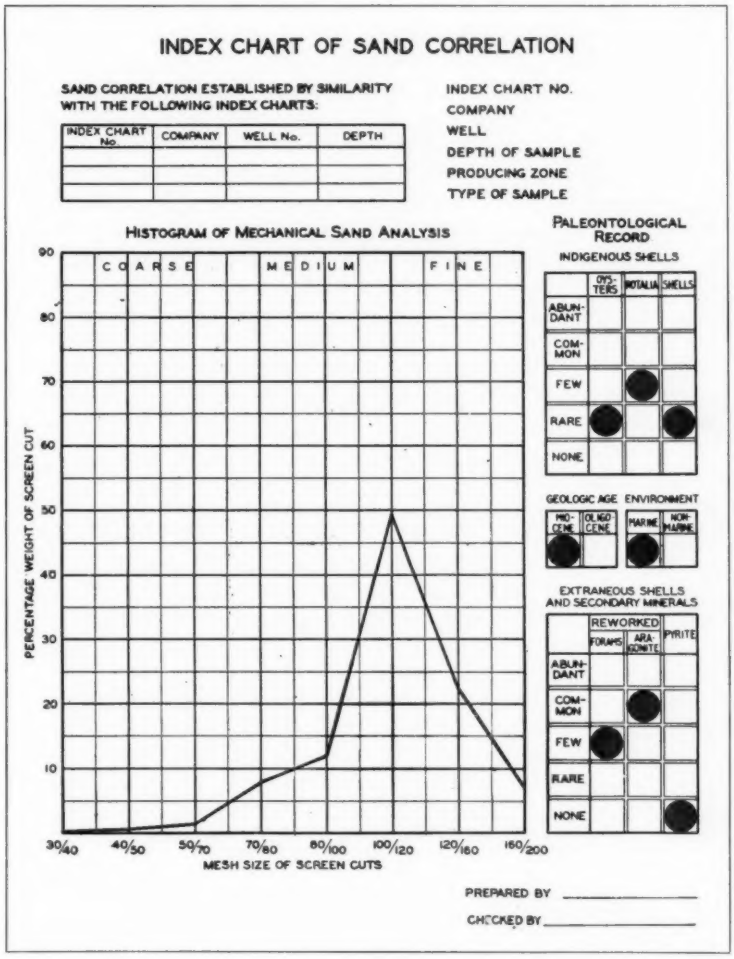
INDEX CHART OF SAND CORRELATION
SAND CORRELATION ESTABLISHED BY SIMILARITY WITH THE FOLLOWING INDEX CHARTS:
INDEX CHART No.
COMPANY
WELL No.
DEPTH
INDEX CHART NO.
COMPANY
WELL
DEPTH OF SAMPLE
PRODUCING ZONE
TYPE OF SAMPLE
HISTOGRAM OF MECHANICAL SAND ANALYSIS
COARSE
MEDIUM
FINE
PERCENTAGE WEIGHT OF SCREEN CUT
90
80
70
60
50
40
30
20
10
30/40
40/50
50/70
70/80
80/100
100/120
120/160
160/200
MESH SIZE OF SCREEN CUTS
PALEONTOLOGICAL RECORD
INDIGENOUS SHELLS
OYSTERS
ROTALIA
SHELLS
ABUNDANT
COMMON
FEW
RARE
NONE
GEOLOGIC AGE
MIOCENE
OLIGOCENE
ENVIRONMENT
MARINE
NON-MARINE
EXTRANEOUS SHELLS AND SECONDARY MINERALS
REWORKED
FORAMS
ARAGONITE
PYRITE
ABUNDANT
COMMON
FEW
RARE
NONE
PREPARED BY
CHECKED BY

FIG. 4

WEIGHING

At the conclusion of the vibrating period, the stack of screens was removed from the shaker and each screen thoroughly cleaned with a stiff brush, care being taken not to damage the screen in the process. The cuts were weighed on a Chain-O-Matic balance to three decimal places. It was found that this balance allowed speedy weighing with extreme accuracy.

METHOD OF PLOTTING

The data obtained by the mechanical analyses of a sample were plotted on a card as shown in Figure 4.

Sheets of Eastman Safety Translite film, 0.015 inch thick and 12 by 20 inches in size, were cut to $5\frac{3}{8} \times 7\frac{1}{4}$-inch rectangles and the form photographed thereon.

FILING

The numbers in the upper right-hand corner of the index chart (Fig. 4) gives, in order of sequence, the code number of the operating company, the number of the well from which the sample was taken, and the serial number of the core. The other entries on the card are self-explanatory.

As already described, only eight screen sizes were used. The percentages of total sample weight caught on each screen were plotted to give the characteristic sand distribution pattern for each sample.

Another method developed for recording the results of sand analyses was the substitution of serial numbers for the graphical method of recording previously described.

The following serial numbers are used to identify the various screen cuts.

Serial Number	*Screen Cut*
1	30/ 40
2	40/ 50
3	50/ 70
4	70/ 80
5	80/100
6	100/120
7	120/160
8	160/200

In making up the serial numbers, the cuts are listed in the order of percentage weight beginning with the heaviest cut. An example is the following analysis of sand core.

Serial Number	*Weight of Sample in Grams*	*Percentage Weight*
1	.1003	1.3
2	.1806	2.4
3	.2714	3.7
4	1.3633	18.4
5	1.2367	16.7
6	2.9766	40.1
7	1.1098	15.0
8	.1820	2.4

The characteristic serial number of this sand is 6-4-5-7-3-8-2-1.

The percentage of the fourth cut (70/80-screen) is arbitrarily designated as the coarseness index. Thus the coarseness index of the sample described is 18.4.

The characteristic serial number of a sand changes as the coarseness of the sand changes. If the coarseness index of the sand increases, the "low" serial numbers such as 2, 3, and 4, move to the left, shifting places with the corresponding "high" serial numbers. If the increase in degree of coarseness is relatively small, only one of the serial numbers would be shifted, the cut that is shifting the position being the one showing the least percentage difference with regard to the cut immediately preceding it. Thus cut number 8 is only slightly greater than cut number 2, and, with a slight increase in coarseness as revealed by the magnitude of the coarseness index, the two cuts, number 8 and number 2, would readily exchange positions. Example:

Well Number	*Depth of Sand in Feet*	*Coarseness Index*	*Serial Number*
A	2,844	18.4	6-4-5-7-3-8-2
B	2,799	25.9	6-4-5-7-3-2-8

If the increase in coarseness is greater, as reflected by higher values of the coarseness index, then two or all of the "low"- figure cuts are shifted, exchanging position with the "high" serial number. Example:

Well Number	*Depth of Sand in Feet*	*Coarseness*	*Serial Number*
A	2,844	18.4	6-4-5-7-3-8-2
B	2,812	32.7	4-6-5-3-7-2-8

When a sand decreases in coarseness, the process of shifting the serial numbers is reversed from the one described.

In addition to the mechanical sand analysis, the paleontological record, the geological age of the formation, and the environment of deposition as determined from the sample were recorded either on tabulated sheets when the sand analysis was expressed by index numbers, or on index charts when the sand analysis was expressed graphically. The paleontological determinations were permanently recorded on the card by punching a hole in the desired square. In cases where the determination was tentative, pencil checks were used *in lieu* of the holes.

The particular problem for which the present method was developed used all these items, although the use of pyrite shown on the charts as a criterion proved to be non-diagnostic and was dropped shortly after the study began.

The card system proved to be speedy and efficient. It is flexible in that heavy-mineral determinations, other types of fossil charts, *et*

cetera, may be substituted for the tables of criteria used in the present work. In other words, it is the method which is of interest rather than the specific example.

The printing of the forms on the photographic film plate was somewhat more expensive than it would have been had the forms been printed on other material. However, use of the film plate had definite advantages.

One advantage was the ease of comparison of several analyses by superposition. At the beginning of the study, the form was printed on a heavy grade of tracing paper, but it was found that constant use of the forms caused the corners to roll up and thus make handling difficult. The film card retains its shape and is easily handled. Another advantage of the film is that it is very durable. Much alteration of data and ink erasing are possible without damaging the film print.

Very clean blue prints can be made from the films, and photostats can be made in considerably reduced size without loss of legibility. If, for example, the prints are to be reduced to a point where they can be used on well logs or cross sections, the area below the sand analysis line on the graph can be painted black to give a silhouette of the sand distribution form, which can stand almost any amount of reduction and is well adapted to purposes of comparison. If the card is laid upon black paper when the photostats are made, the holes show up as black circles and are readily legible. Furthermore, any written notes which are to be kept on the card may be written on it with the assurance that they may be easily read and removed when they are no longer necessary.

The size and stiffness of the card facilitates filing in a small file box. If the index system described here is used as a basis for the filing system, any particular card or cards are readily accessible.

A great abundance of information may be filed permanently on the card in such a compact space that any desired data may be quickly found. Especially is this an advantage over the average paleontological report, which is ordinarily difficult to remember in detail.

The cards are small enough to be lined up on a table according to depth and positions of the wells so that the sand characteristics may be compared and the progressive environmental history easily seen. This method of correlation by lining-up of the index cards is very desirable inasmuch as it shows the vertical and lateral relationships of the sediments being considered.

PALEONTOLOGICAL DATA

The routine method of preparing and examining cores and cuttings for microfauna was followed. The paleontologists making the

examinations noted on a permanent record the following items: depth of sample; description of sample; kind of sample (cores, cuttings, *et cetera*); whether or not indigenous or reworked faunal remains were present, and if so, whether they were rare, few, common, or abundant; and the paleontological and geological classification of the sample. The quantitative analyses of sand and fossils derived from cuttings were not used.

The quantitative recording of indigenous and extraneous shells under separate headings led to the interesting observation that wherever the indigenous shells were abundant, the reworked shells are absent or rare, and *vice versa*.

A tentative explanation of this phenomenon is offered, relating the fact to the conditions of depositional environment. Thus, in the presence of wave action, the existence of which may be inferred by the abundance of worn fragments of oyster shells, it is reasonable to expect that the small, delicate tests of the reworked extraneous fauna have been destroyed. As further proof of the correctness of this opinion, mention is made of the fact that the foregoing relationship, which was noted without exception in all the sand samples examined, does not hold true in shale samples which were deposited in quiet water.

APPLICATION OF METHOD

Studies of sedimentation problems and screen analysis in the past have shown that the properties characteristic of the samples from a closely restricted portion of the geologic column are somewhat related, but that on the whole no exact comparison could be made between any two samples. The reason for this fact is obvious. While it is possible that two sands, alike in all details, could be deposited near each other on a beach, yet the probability that cores from adjacent wells will yield identical screen analyses and still be exactly comparable in paleontological details is rather remote. As a matter of fact, screen analyses from two sections of the same core are not alike in all details, although they may be so close that when plotted, as described, little doubt can be entertained as to their relationships.

Thus it can be stated that if conditions of deposition remain constant for any length of time, the sediments on a somewhat restricted area of the sea bottom have characteristics which, though not identical, are similar and recognizable. The conditions prerequisite to deposition of like material in an appreciable vertical and horizontal range are: constant depth of water, constant isostatic relation of land and sea, constant source of similar material, and unchanging relations of currents, tidal movements, *et cetera*.

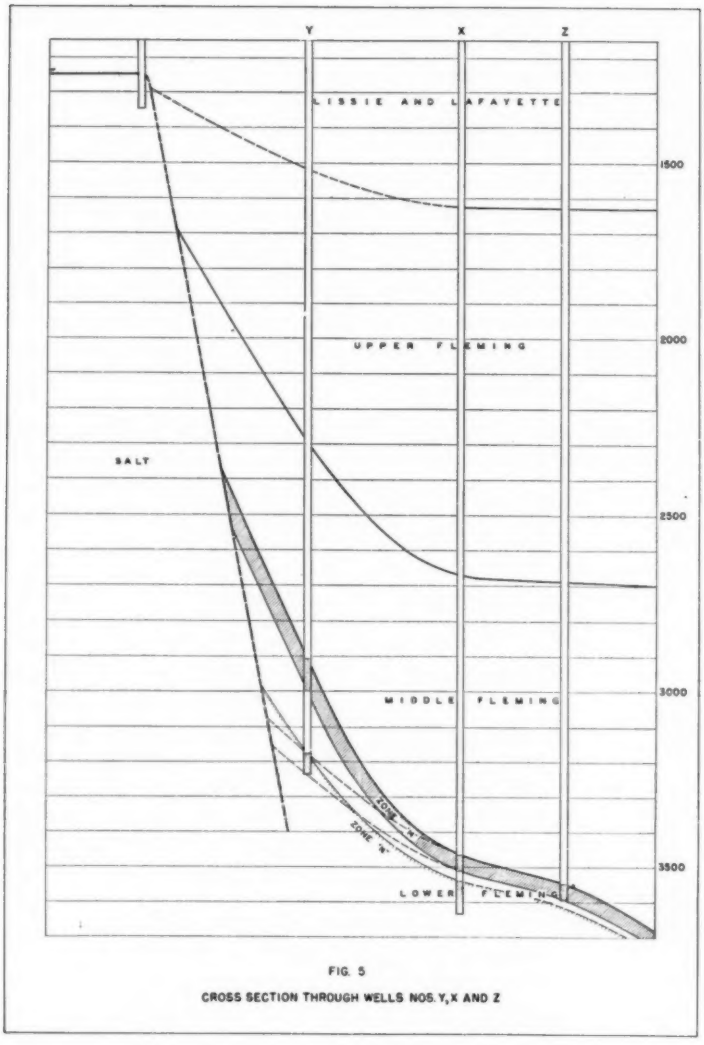

FIG. 5

CROSS SECTION THROUGH WELLS NOS. Y, X AND Z

FIG. 5

If conditions remain constant for increasing lengths of time, so do chances for increased vertical range of correlations by screen analyses. In like manner, so do the chances for greater lateral range of correlation increase.

If mechanical analyses alone are used for correlation, the chances for a reversion after change in condition in sedimentation to the original type of sediment lead to confusion and error in correlation. However, if paleontological data are used in conjunction with mechanical sand analyses, the chances for such confusion are greatly reduced and in addition closer correlation is permitted.

EXAMPLE OF CORRELATION BY MEANS OF INDEX CHARTS

The following example is taken from an actual case but the designation of the wells is fictitious. The problem is to determine whether the oil sand topped at 3,460 feet in well X (Fig. 5) is the same as the producing zone topped at 3,212 feet in well Y or that topped at 2,947 feet.

All of the index charts available for the oil sand zone topped at 3,460 feet in well X, as well as the index charts available for both oil sand zones in well Y, are shown in Figure 6.

Figure 7 shows three index charts from well X and the correlating three index charts for well Y. It is to be noted that the three index charts of the two wells are in the same sequence and that approximately the same interval is found between what are considered to be the correlating sands.

There are several index charts in the lower sand zone of well Y (Fig. 6) that are similar to the first two index charts (Fig. 7) of well X. The third index chart of well X (2-X-03), however, shows the presence of indigenous marine shells, whereas none of the index charts of the lower sand of well Y shows any indigenous shells. All of the remaining index charts of well X show the presence of reworked Cretaceous shells, whereas none of the index charts of the lower sand of well Y shows any reworked shells. The only charts of well X that could possibly be correlated with any of the charts in the lower sand of well Y are the first two charts, which show a medium-grained sand with no indigenous or extraneous shells. Such sands are very common and can not be considered as diagnostic.

By referring to Figure 7 it will be noticed that the first correlating index charts (2-Y-03 and 2-X-02) show a medium sand with no indigenous or reworked fossils. The second pair of index charts (2-Y-05 and 2-X-03) show a medium-fine sand with indigenous marine shells. The paleontological record, however, is not identical. The sample from

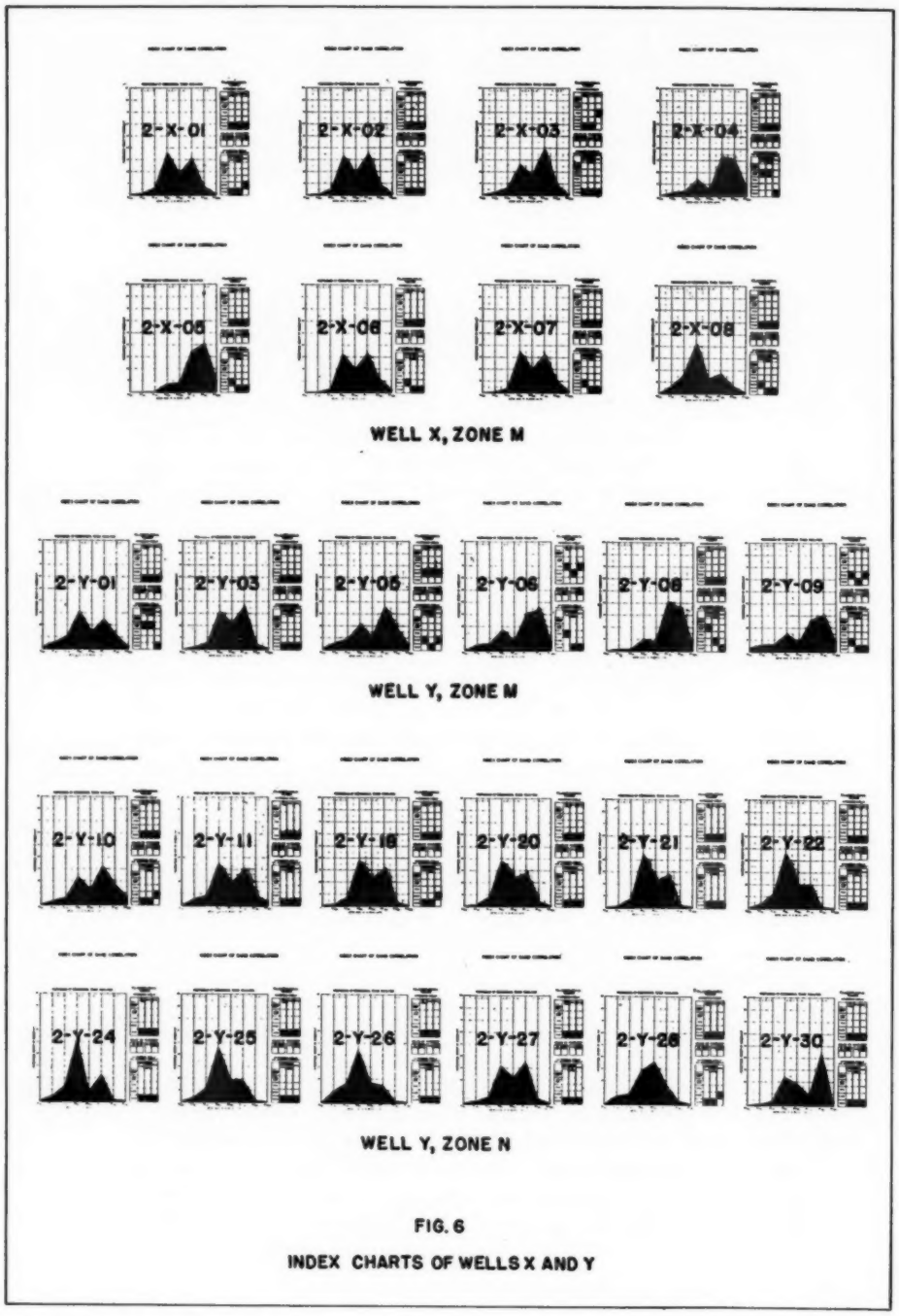

FIG. 6.—The detail of these charts, here illegible, may be seen in enlarged index chart shown as Figure 4.

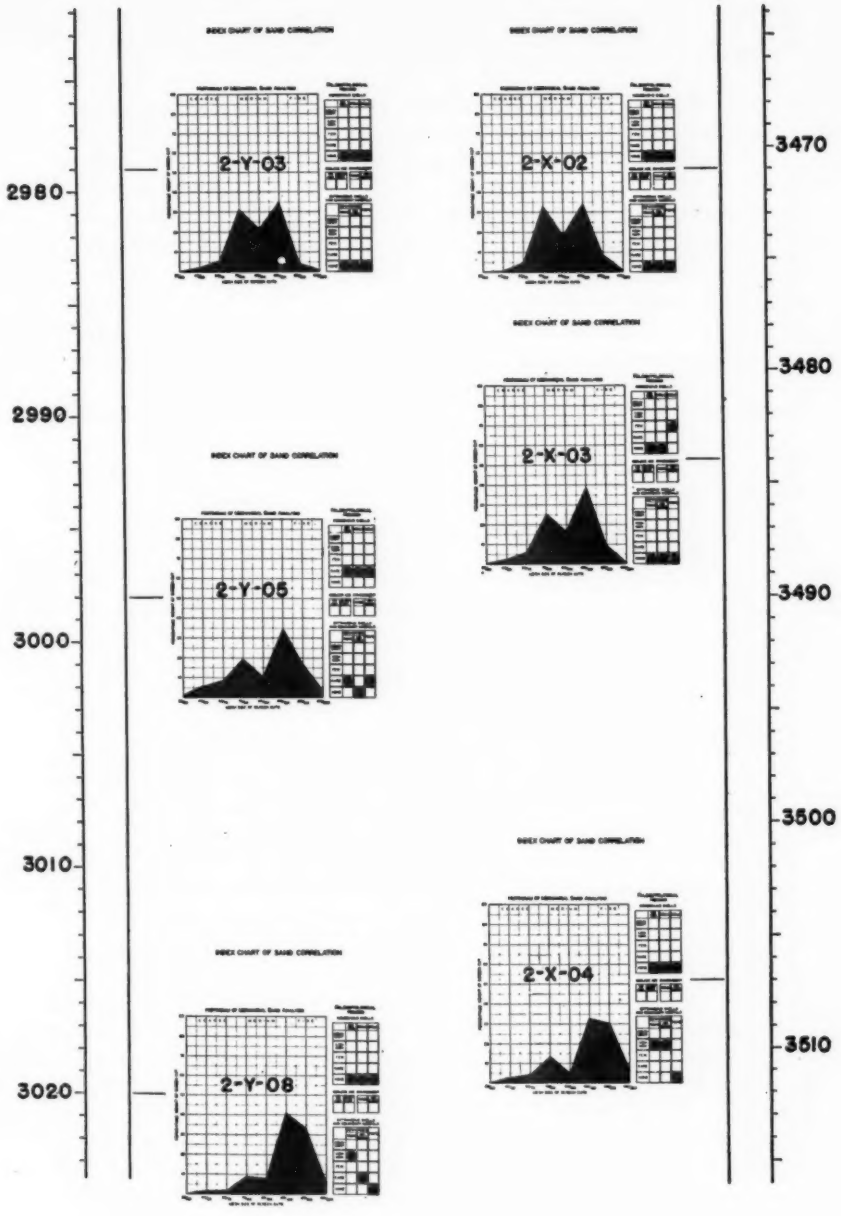

FIG. 7
USE OF INDEX CHARTS IN DETAILED SAND CORRELATIONS IN THE M ZONE

FIG. 7.—The detail of these charts, here illegible, may be seen in enlarged index chart shown as Figure 4.

well Y shows rare reworked foraminifera and no reworked aragonite prisms (*Inoceramus* ribs), whereas the sample from well X shows no reworked foraminifera and no reworked aragonite prisms. The differences between "none" and "rare" is slight. If a large sample had been used, then the difference might have been significant but when in a 5- or 10-gram sample one or two reworked foraminifera are found, whereas none was found in the other sample, the difference in recording can easily be attributed to the scarcity of the reworked fossils and the reduced size of the sample rather than to an important difference in environment of deposition or age of the two samples. However, should one sample show no reworked fossils, whereas the other sample showed a common occurrence or an abundant occurrence of reworked fossils, such two samples would not be considered to correlate. The same second pair of correlating index charts shows a difference in the record of indigenous shells. The two index charts may not represent exactly the same correlating sand. As a matter of fact, the second index chart of well X shows the analysis of a sand occurring 13 feet below the sand shown on the first index chart, whereas the second index chart of well Y shows the analysis of a sand occurring 19 feet below the sand shown on the first index chart of the same well. The fact that the same index chart showed evidence of marine environment in a zone where such evidence is scant is considered sufficiently significant to justify the correlation of the two sands showing a marked similarity of sand-grain distribution.

The third set (2-Y-08 and 2-X-09) of correlating index charts (Fig. 7) shows a fine sand with no indigenous marine fossils but with a common occurrence of reworked Cretaceous foraminifera. The occurrence of aragonite prisms is recorded as rare in well Y and common in well X and the two sands would not have been correlated were it not for the fact that the reworked Cretaceous foraminifera are common in both samples. An examination of the sand analysis graph of chart 2-Y-08 shows that the sand is finer than the sand shown on chart 2-X-04, with which it was correlated, and coarser than the sand shown in 2-X-05. The sand shown in chart 2-X-04, which was found at 3,507 feet, shows an abundance of reworked aragonite prisms, whereas the sand occurring at 3,515 feet shown in chart 2-X-05 shows no aragonite prisms. It is, therefore, reasonable to expect that some sand between 3,507 and 3,515 feet, of a degree of coarseness approaching that of the sand shown in 2-Y-08, would show an occurrence of reworked aragonite prisms that would be intermediate between those shown by the index charts 2-X-04 and 2-X-05 and, therefore, would approach the occurrence shown by the index chart 2-Y-08.

Such an analysis of index-chart data as that just given in detail may seem awkward, but, with a little practice and the index charts all lined up on a table, the entire process becomes very elucidating and simple.

As mentioned before, the use of the index charts is not limited to correlation.

It is to be noted that the three correlating index charts occur higher in the sand zone in well X than in well Y. This fact is not caused by improper logging of the top of the sand. On the contrary, the location of the correlating sands higher in the section in the down-dip well is a general phenomenon encountered in the area and zone being considered and is due to the relationship of deposition to the concomitant movement of the dome.

Figure 8 shows the correlating sand zone referred to in wells X and Y. The section is lined up on the basis of correlating sands and includes the adjoining wells W and Z.

The sand zone shown, hereafter referred to as Zone M, rests unconformably on a fresh-water marl referred to by the drillers as shale and lime. The shale, in addition to being calcareous, contains soft white calcareous masses; hence its description in the drillers' log as shale and lime. This marl overlies the non-marine unfossiliferous sand encountered in well Y (Zone N) at 3,212 feet, to which reference has already been made.

Five distinct sand members have been differentiated in Zone M in the section shown in Figure 8. The sand-determination charts which served to effect this correlation have been discussed already in the case of the upper three sands. The correlation of the lower two sand members was made by similar reasoning and using the same type of evidence, but a discussion of the evidence is omitted from this paper for the purpose of conciseness.

From the data derived from the sedimentation study and plotted on the index cards, the following geological history of this particular section may be derived.

At the close of the period of deposition of the lower non-marine sand and fresh-water marl discussed (shown on Figure 8 as the intermediate shale of lower Fleming age) there followed a period of gradual submergence during which the sands of Zone M were deposited. The submergence continued through the period of deposition of marine shales overlying Zone M.

The non-marine sediments of Zone N of Miocene age overlie the marine Oligocene. During the period of emergence that followed the close of the Oligocene and prior to the deposition of Zone M some

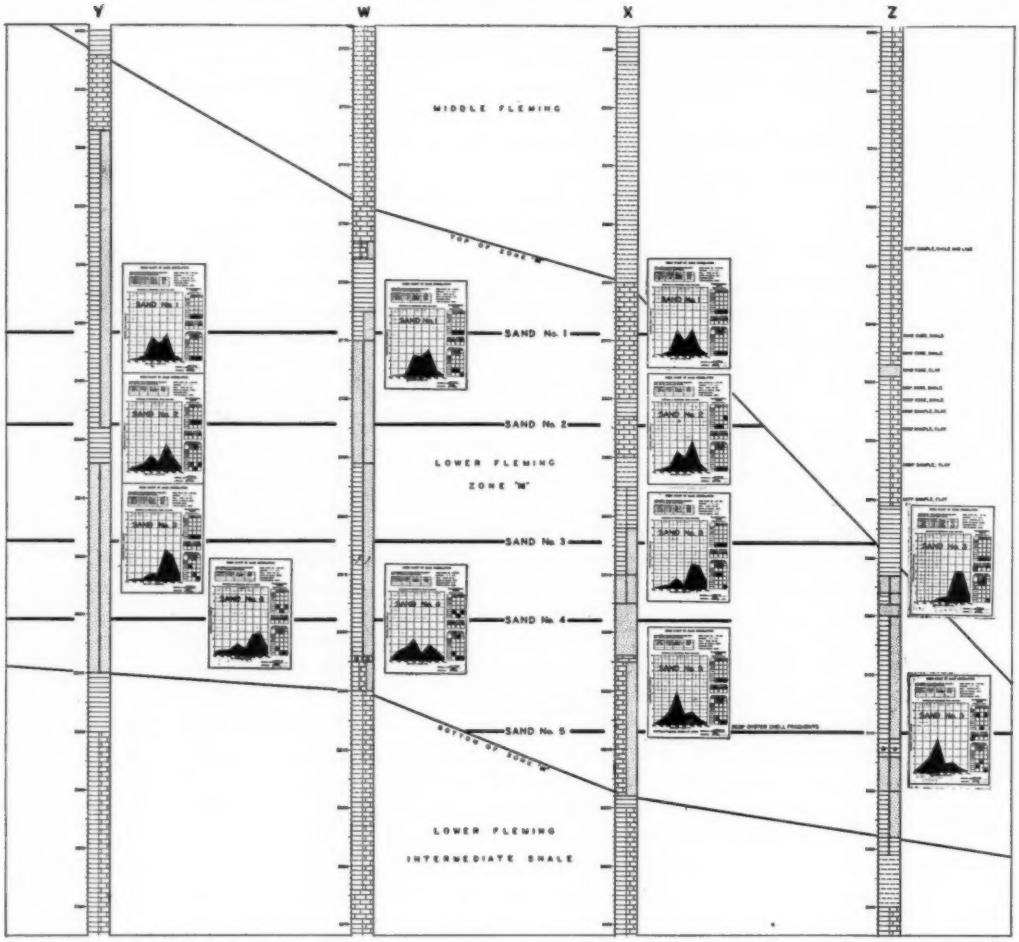

FIG. 8

SAND MEMBERS WITHIN ZONE "M"

SHOWN IN ATTITUDE OF DEPOSITION

FIG. 8.—The detail of these charts, here illegible, may be seen in enlarged index chart shown as Figure 4.

of the Upper and Middle Oligocene in the area of uplift was subjected to erosion. Without going into any details in the present paper, mention is made of the fact that the unconformable contact of the Lower Miocene with the Lower Oligocene close to the dome and the flanking position of the Middle and Upper Oligocene sediments off the dome are the result of the erosion of a once continuous series of sediments from the crest of the uplift rather than non-deposition. There is strong evidence on the southeast flank of the dome that during Lower Miocene time a large amount of Oligocene material was eroded off the dome proper and re-deposited as reworked material on the flanks in the surrounding shallow sea.

At the close of the time of deposition of the fresh-water marl shown in Figure 8 there followed a submergence of the area, as a result of which shore-line sands were deposited in the shallow seas. Thus, sand No. 5 (Fig. 8) did not extend as far up the flank of the dome as the sands of wells Y and W. Then followed the deposition of sands No. 4 and No. 3, each of which extended a little farther toward the center of the dome than the member immediately underlying. Off the dome these sands change to shale, following the normal sequence of deposition.

Thus, the sand present in well Y at 2,950 feet is represented by shale in wells W, X, and Z, while sand No. 1, present in wells Y, W, and X, is not present in well Z, *et cetera*. Well Z was drilled twice and carefully cored. There is no reason to believe that there is a sand zone formation encountered in well Z and logged as shale. It may be argued that the disappearance of the sand in wells Z, X, and W is due to faulting, but the same type of occurrence is so general and consistent that such an assumption could not explain the other occurrences throughout the field. Furthermore, it would seem awkward to have a fault explain the lack of deposition of sand No. 5 in wells Y and W and another fault explain the lack of deposition of sand No. 1 in well Z. In general, the evidence shows that a single sand member which has been deposited on the flanks of the dome extends over a very limited area. Therefore, the producing zone, made up as it is of many local sand members, shows great variation in thickness, the variations, however, being closely related to the tectonic movements of the dome during the deposition of the sediments.

While in general the deposition of sands in superimposed layers moving inland with the encroaching sea is a well recognized regional feature, yet it has not been commonly recognized and has not been fully appreciated in its occurrence over small areas in the vicinity of salt domes.

Another interesting study to be derived from the examination of the index charts is with regard to cycles of deposition as reflected by the lithological characteristics of the sand and shown by the index charts. The group of index charts of the lower sand of well Y, shown at the bottom of Figure 6, is an example of a depositional cycle. Beginning with card 2-Y-30 the sand is fine, gradually becoming coarser as shown in 2-Y-28, 2-Y-25, 2-Y-24, *et cetera*, although remaining essentially a medium-grained sand. At the other end of the cycle, card 2-Y-17 shows a sand slightly finer than the one shown in 2-Y-18, while the sand shown in 2-Y-16, at the end of the cycle, is the finest of the three sands last mentioned. This sand being non-marine and unfossiliferous, the paleontological cycle which somewhat commonly accompanies the sedimentary cycle can not be observed. Other typical sand depositional cycles have been noted in the sand study of the dome.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 10 (OCTOBER, 1937), PP. 1333-1339, 1 FIG.

APPLICATION OF X-RAY CRYSTAL ANALYSIS TO A PROBLEM OF PETROLEUM GEOLOGY[1]

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ABSTRACT

The powder method of X-ray analysis of mineral mixtures has been applied to selected drill samples from several geological formations of some western Kansas oil wells. The diffraction patterns obtained were interpreted to show the individual minerals present, and the relative abundance of each, in the drill cuttings.

The data for wells rather widely separated geographically show a distinct correlation between the type X-ray diffraction pattern obtained and the member of the formation from which the sample was obtained.

A great possible usefulness of the method to petroleum geology is indicated.

The definite identification of the exact geological stratum from which a drill sample originates presents a problem which has been only partly solved by microscopic examination and chemical analysis. The mineral constituents of a sample can only be guessed from the latter, and can be determined with no great certainty, even with the most refined technics of microscopy. Although these have been indispensable in directing drill operations in the past and will certainly remain so in the future, a sure and unquestionable means of mineralogical analysis of finely divided specimens and complex mixtures would be welcomed by geologists as an immensely valuable aid in their work. Such a method is to be found in the powder method of crystal analysis by X-ray diffraction.

The pertinent facts concerning the use of X-ray diffraction for mineralogical analysis are summarized in the following statements.

1. Each chemical compound, or distinct mineral, when pulverized and placed in the path of a monochromatic pencil of X-rays, gives rise to a diffraction pattern, which is unique for that substance. This pattern may be recorded photographically.

2. The same substance invariably produces the same diffraction

[1] Manuscript received, May 20, 1937.

[2] General Electric X-Ray Corporation, Chicago. The writers wish to express their gratitude to the General Electric X-Ray Corporation for the use of the General Electric-Hayes X-Ray diffraction unit used in this investigation, and to the following oil companies for the samples used: Carter Oil Company, Vickers Petroleum Company, and Sinclair-Prairie Oil Company.

[3] The Eldon Means Company, Wichita.

[4] Vickers Petroleum Company, Wichita.

pattern, which is different from that obtainable from any other substance.

3. Different polymorphic forms of the same compound, or mineral, show different X-ray diffraction patterns, and so can be distinguished with certainty. Thus flint, which is crypto-crystalline quartz, shows the same pattern as a powder prepared from a large single crystal of alpha-quartz, but cristobalite and tridymite give patterns different from alpha-quartz, and different from each other.

4. For a mixture of minerals, each mineral present gives its own pattern, regardless of the other constituents, and the resulting pattern is made up of the superimposed patterns of all the individual minerals present.

5. By comparing the pattern for a mixture with those for pure minerals it is a simple matter to identify beyond any reasonable doubt the minerals present, and, which is of almost equal importance, it is easy to make an estimate of the relative amounts of each constituent mineral.

It is to be emphasized that this method not only shows the elements present, but does so by showing their true state of chemical combination. The only limitation involved is that any mineral must be present to the extent of one or two per cent before enough of its individual pattern shows to provide positive identification.

The investigation to be described was undertaken with the thought that such a mineralogical analysis would be of great help to the other methods used to direct drilling operations. It was considered probable, even, that a definite differentiation between various members of a geological formation might be made on the basis of the type X-ray diffraction pattern obtained, at least within one geological province. Though this latter point has not yet been proved conclusively, an encouraging correlation has been found which justifies a preliminary report on work in progress.

EXPERIMENTAL PROCEDURE

The technic of the Hull-Debye-Sherrer "powder" method of crystal analysis by X-ray diffraction has been described many times,[5] hence no detailed account is needed here. The particular technic used

[5] A. W. Hull, "A New Method of Chemical Analysis," *Jour. Amer. Chem. Soc.*, Vol. 41 (1919), p. 1168.
G. L. Clark, *Applied X-Rays*, 2nd ed., McGraw-Hill Book Company, New York (1932).
W. P. Davey, "Chemical Analysis by X-Ray Diffraction Methods," *A.S.T.M. Symposium on Radiography and X-Ray Diffraction Methods* (Amer. Soc. for Testing Materials, Washington, D.C., 1937).

in this investigation was the so-called "wedge" technic[6] with a modified Sherrer camera, in which the apex of a wedge of powder is substituted for the conventional cylindrical specimen.

To obtain reference patterns of the constituent minerals, the drill-cutting samples were examined under low-power magnification, and grains selected to represent each of the different appearing minerals. From the X-ray diffraction patterns of the 30 specimens selected in this manner 6 distinct minerals were recognized. These were designated as A, B, C, D, E, and F. A and B are alpha-quartz and calcite, respectively. C has been segregated in nearly pure form. Its pattern is very similar to that for calcite, and matches the calculated pattern for dolomite.

D, E, and F were found to be intimately associated with A, B, or C, or mixtures of these. Though they have not been isolated or identified, they do represent distinct minerals, since the diffraction lines for each of them are invariably associated together in the same order of relative densities.

For more than 100 drill-cutting and outcrop samples examined so far, representing 13 different geological strata, these 6 minerals were sufficient to account for practically all the diffraction lines observed. In the tables the letter X designates the appearance of lines not coming from one of the 6 minerals. It does not represent any one mineral for the whole set of samples, but may vary from series to series. Except for certain isolated samples, the X minerals are not present to any very large extent, and ordinarily appear only in shaly samples.

To classify the type diffraction patterns obtained, the lines appearing on each film were numbered and measured. The measurements were listed in the order of decreasing line densities, and checked against similar measurements for the standard minerals. In this manner the individual minerals in a specimen could be identified, and listed in their proper order of decreasing abundance. The resulting series of letters then designates the type pattern for that specimen. For example, the letters ABC indicate that the sample consists principally of quartz, calcite, and dolomite, with quartz the most prominent, and dolomite present in least amount.

RESULTS AND DISCUSSION

The results for drill samples from various limestone strata encountered at different depths in the same drill hole are tabulated in

[6] G. L. Clark and D. H. Reynolds, "Quantitative Analysis of Mine Dusts," *Ind. Eng. Chem. Anal. Ed. 8*, 36 (1936).

Table I. The patterns obtained have been correlated so far as was possible with the type patterns of outcrops, or similarly identified samples from other localities.

TABLE I

CHANGES IN TYPE PATTERN OF DRILL SAMPLES FOR SUCCESSIVE DEPTHS. DRILL HOLE IN SEC. 25, T. 15 S., R. 24 W., KANSAS

Sample	*Depth in Feet*	*Formation*	*Pattern*	*Type*	*Formation Indicated*
161	2,590–2,600	Fort Riley	ECA	ECA or BCA	Fort Riley
162	2,650–2,660	Florence flint	ACE*	A, AC, AB	Florence flint
163	2,900–2,920	Cottonwood	CEABD	BAC	?
164	2,940–2,950	Neva	BECA	BA†	Neva
165	3,060–3,070	Americus	BAEC	BAXC	Americus
166	3,260–3,270	Howard	BADX	BAD†	Howard
167	3,410–3,420	Topeka	BACDE	BAC	Topeka
169	4,311–4,313	Mississippian	CAB	ACD	?
169 a	4,313–4,315	Mississippian	CAX	or ABD	?
169 b	4,315–4,318	Mississippian	CABX		?
169 c	4,318–4,320	Mississippian	ACDX		Mississippian
170	4,418–4,422	Viola-Simpson	ABEX	B†, BC?, or	Mississippian
170 a	4,422–4,430	Viola-Simpson	ABEDX	CB?	Mississippian
171	4,440–4,445	Viola-Simpson	BAC		?
171 a	4,445–4,450	or Arbuckle	BADC		?
172	4,499–4,502	or Arbuckle	BCX		Viola
172 a	4,502–4,505	or Arbuckle	BC		Viola
172 b	4,505–4,510	or Arbuckle	CB		Viola
173	4,538–4,543	Arbuckle	CA	AC or CA	Arbuckle
173 a	4,543–4,547	Arbuckle	CA	AC or CA	Arbuckle
174	4,599–4,603	Arbuckle	ACX	AC or CA	Arbuckle
174 a	4,603–4,608	Arbuckle	ACX	AC or CA	Arbuckle
175	4,699–4,706	Arbuckle	CAD	AC or CA	Arbuckle
175 a	4,706–4,708	Arbuckle	CAX	AC or CA	Arbuckle
175 b	4,708–4,711	Arbuckle	CA	AC or CA	Arbuckle
176	4,719–4,726	Arbuckle	CA	AC or CA	Arbuckle

* A bar over a letter indicates that the mineral so overlined is present in rather small amounts.
† From outcrops.

It will be noted that good agreement is found for the strata above the Mississippian limestone, except for the Cottonwood. The Mississippian limestone appears to have been anticipated prematurely and relinquished too soon, making it, together with the Viola and Arbuckle strata, a matter of 100 feet out of place. This conclusion assumes, of course, that the Mississippian and lower formations should show a mineralogical relationship to the same strata elsewhere, as is apparent for strata above the Mississippian. That this is not asking too much is shown by the results in Table II for the series from rather widely separated localities.

TABLE II

CORRELATION BETWEEN DIFFERENT LOCALITIES

TABLE II

CORRELATION BETWEEN DIFFERENT LOCALITIES

Formation	1			2			5			6			7		
	Sec. 25, T. 15 S., R. 24 W.			Sec. 30, T. 14 S., R. 2 W.			Sec. 26, T. 17 S., R. 9 W.			Sec. 33, T. 21 S., R. 6 W.			Sec. 26, T. 23 S., R. 4 W.		
	Depth		Results	Depth		Results	Depth		Results	Depth		Results	Depth		Results
Florence flint	2,650–2,660	162	ACE				1,510–1,520	63	ABC						
								63a	AB						
Howard	3,260–3,270	166	BADX				2,345–2,355	67	BADC						
Mississippian	4,311–4,313	169	CAB												
	4,313–4,315	169a	CAX												
	4,315–4,318	169b	CABX												
	4,318–4,320	169c	ACDX	2,700–2,710	1	ACBD				3,590–3,600	59	ABED	3,240–3,250	19	ACB
				2,710–2,715	1a	ACD					59a	ABED		19a	ACX
Viola				3,270–3,273	3	AFDCX				3,980–3,990	60	ABDEC			
				3,273–3,275	3a	ACF									
				3,275–3,280	3b	ACX									
Arbuckle	4,538–4,543	173	CĀ	3,480–3,485	4	AC	3,187–3,197	7a	CBA	4,082–4,092	61	ABCDE	3,090–3,100	10	CBAED
	4,543–4,547	173a	CĀ	3,485–3,490	4a	CA		70a	C		61a	ABDCFE		10a	CAEB
	4,599–4,603	174	$AC\overline{X}$										3,300–3,310	12	CA
	4,603–4,608	174a	$AC\overline{X}$											12a	CA
	4,699–4,706	175	$CA\overline{D}$											12b	CA
	4,706–4,708	175a	$CA\overline{X}$										3,500–3,510	14	AC
	4,708–4,711	175b	CA											14a	$CA\overline{DB}$
	4,719–4,726	176	CĀ												

Formation	8			9			10			11			12		
	Sec. 17, T. 22 S., R. 3 W.			Sec. 19, T. 22 S., R. 3 W.			Outcrop Eastern Kansas			Sec. 30, T. 2 S., R. 7 E. Okla.			Sec. 27, T. 7 N., R. 4 E.		
	Depth		Results	Depth		Results				Depth		Results	Depth		Results
Florence flint							157	B						Cores	
							158	BĀ							
Howard							159	BAD							
Mississippian	3,170–3,180	55	ABCD	3,150–3,160	57	ABX									
					57a	ABD									
Viola	3,570–3,580	56	ADF							3,560–3,570	47	ABDX			
		56a	ADFC							3,570–3,580	48	ABDX			
										3,620–3,630	49	B	4,211–4,218	30	B
										3,630–3,640	50	B		29	B
Arbuckle															

In Table II the regularity observed in the Mississippian, Howard, and Arbuckle samples is quite gratifying. Three of the Florence flint samples fit in very well also, but in sample 157 quartz is entirely absent, and sample 158 is very low in this mineral, which certainly should be found in a flint.

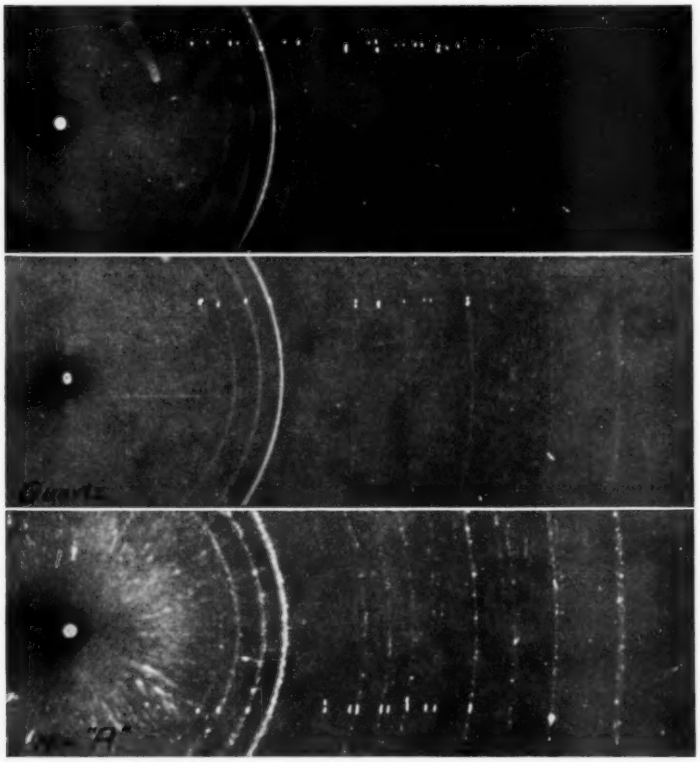

FIG. 1.—Photographs of X-ray diffraction patterns of samples of Florence flint (top), pure quartz (middle), and mineral *A* (bottom). Notice identity of mineral *A* with quartz.

It should be noted that for the Viola series the two core samples prove to be pure calcite, while all the other samples, except 49 and 50, show a predominance of quartz with the almost complete absence of calcite. Samples 47, 48, and 60 show a close relationship to the Mississippian series. These facts appear to throw some doubt upon the previ-

ous identification of these samples, although an effort was made to use only samples whose classification was certain.

Tables I and II show results from 55 of more than 100 samples which have been examined by the X-ray method. It is true that a sufficiently great number of samples have not yet been analyzed to show the ultimate value of the method in identifying geological strata. However, the results presented do prove that X-ray diffraction may be expected to be of enormous practical aid to the petroleum geologist, particularly if fossiliferous evidence is lacking or confusing. The usefulness of the method is bound to increase as the number of drill holes surveyed increases, and more extended correlations between different localities are made available. The investigation started here is still in progress, and will be reported more completely at a later date.

CONCLUSIONS

X-ray diffraction by crystalline powder offers a method of determining the individual minerals present in a drill-cutting sample, and of estimating the relative amounts of each mineral.

Data for geological strata from several oil wells in western Kansas show a definite correlation between the type X-ray pattern obtained and the member of the formation from which the sample was obtained.

The types of X-ray diffraction patterns (Fig. 1) for various limestone strata encountered at different levels in a single drill hole are tabulated. These indicate that the method has a great possible usefulness to the petroleum geologist in directing drilling operations.

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GEOLOGICAL NOTES

VOLCANIC TUFFS OF SANTA LUCIA RANGE AND MIOCENE PALEOGEOGRAPHY OF SALINAS VALLEY, CALIFORNIA

The Miocene paleogeography, age of faulting, and present structure of the lower (northern) Salinas Valley, lying between Sierra de Salinas (northern Santa Lucia Range) on the west and the Gabilan Range on the east, have been variously interpreted by many geologists. In recent years Clark has made several contributions.[1] In his most recent discussion appears the following statement which apparently was the basis for revising his former interpretation of the Miocene paleogeography of the lower Salinas Valley.

> The writer formerly thought that there was a channel between Toro Mountain and the Gabilan Mountains during the Miocene; this area was called the Salinas graben. The work of C. L. Herold . . . upon the Miocene sediments west of Toro Mountain appears to show that these sediments were derived in part from certain distinctive volcanic rocks which are known only in the northeast part of the Gabilan Mountain block. There are no records of marine Miocene or Pliocene sediments underneath the alluvium of the Salinas Valley. Thus, it would seem probable that the Salinas graben had a much later origin than was at first believed.[2]

It is feared that there has been a misinterpretation of the character of the volcanic detritus in the Miocene sediments, particularly with respect to the mode of transportation from its source, which is believed to have been in the Pinnacles area.[3]

It has apparently been assumed that the volcanic débris was transported by westward-flowing streams across the area that is now the western slopes of the Gabilan Range and the lower Salinas Valley, ultimately being deposited in the Miocene seas west of the "Toro Mountain block," or Sierra de Salinas. Elsewhere in this *Bulletin* the writer[4] has attempted to demonstrate that the volcanic detritus,

[1] B. L. Clark, "Tectonics of the Valle Grande of California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 203; "Tectonics of the Coast Ranges of Middle California," *Bull. Geol. Soc. America*, Vol. 41 (1930), pp. 800–01; and "Tectonics of the Mount Diablo and Coalinga Areas, Middle Coast Ranges of California," *Bull. Geol. Soc. America*, Vol. 46 (1935), p. 1051.

[2] *Bull. Geol. Soc. America*, Vol. 46 (1935), p. 1051.

[3] C. L. Herold, "Further Evidence for Age of Volcanism, Pinnacles National Monument, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 10 (October, 1937), pp. 1341–44.

[4] *Op. cit.*, pp. 1342–43.

which is tuffaceous, was carried through the air rather than by streams. Thus it is obvious that the presence or absence of a graben could have had little or no effect upon transportation and distribution of the tuffs occurring in the Miocene sediments of the Salinas Quadrangle.

It is true, however, that water-worn pebbles and cobbles of rhyolite possessing marked petrographic similarity to the Pinnacles rhyolite do occur in the Paso Robles (Pliocene (?)-Pleistocene) formation on the north slopes of Sierra de Salinas. The source of this material was undoubtedly likewise in the Pinnacles area, and most certainly transported by streams. By virtue of the later age of these beds, this evidence has little bearing on the question of the Miocene paleogeography.

It is not the writer's purpose in this paper to make further deductions of the Miocene paleogeography, or to discuss the present structure and age of faulting of the lower Salinas Valley. The sole motive is to call attention to the unfortunate misinterpretation, and perhaps to forestall any perpetuation that might possibly occur.

C. LATHROP HEROLD

SHELL PETROLEUM CORPORATION
TYLER, TEXAS
June 25, 1937

FURTHER EVIDENCE FOR AGE OF VOLCANISM, PINNACLES NATIONAL MONUMENT, CALIFORNIA

In his recent publication on the geology of the Pinnacles National Monument[1] in the Gabilan Range of California Coast Ranges, Andrews states that the volcanism of that area "began in late Vaqueros time and continued to that of lower Temblor"[2] (or, from upper Lower to lower Middle Miocene). His evidence is based on the presence or absence of volcanic material in the near-by Tertiary sediments, and on generalized correlation with recognized Vaqueros-Temblor volcanism elsewhere in California. Due to the lack of fauna in the Tertiary sediments, Andrews' dating is "somewhat uncertain," according to his own statement.[3]

Two volcanic tuffs which are believed to have had their origin in the Pinnacles area occur in the Salinas and Jamesburg quadrangles

[1] Philip Andrews, "Geology of the Pinnacles National Monument," *Univ. California Bull. Dept. Geol. Sci.*, Vol. 24 (1936), pp. 1–38.

[2] *Ibid.*, p. 23.

[3] *Ibid.*, pp. 10, 12, 22.

of the northern Santa Lucia Range, 25 miles west. They are intercalated in a fossiliferous marine sequence which suggests that the Pinnacles volcanism continued to uppermost Miocene and possibly to lowermost Pliocene time.

One of these is a lustrous, silver-gray vitric tuff, averaging about 8–12 feet thick, which occupies a position about 100–125 feet below the top of the local, near-shore sandy facies of the Monterey formation. In the Salinas quadrangle the tuff is exposed on the slopes bordering Corral de Tierra and in the foothills immediately southwest of Spreckles, where it occurs with two similar, but less thick and less consistent beds of intimate association. It is also found along the south slope of Buckeye Ridge in the Jamesburg Quadrangle. Microscopic examination of numerous samples from widely separated localities shows the tuff to be composed almost wholly of fine needles and angular fragments of volcanic glass averaging 0.1 mm. in diameter. It is remarkably free of foreign detritus from near-by granitic masses from which were derived the sediments of the super- and subjacent beds. The composition of the glass is rhyo-dacitic, as determined from the consistent refractive index of $n = 1.506 \pm .004$. Sharp depositional contacts with the marine sediments with which it is interbedded are characteristic.

That the source of this tuff was in the Pinnacles area is indicated by two groups of evidence. The first evidence is the close agrreement in composition of vitric products in both areas, namely, $n = 1.496 \pm .004$ (average for Pinnacles),[4] and $n = 1.506 \pm .004$ (Salinas-Jamesburg). Rhyolitic products, particularly those issuing from explosive phases, predominate at the Pinnacles.[5] The second evidence is the lack of other known possible sources in temporal agreement and within reasonable distance. The rhyolite flows and pyroclastics south of San Juan Bautista[6] are almost contiguous, and apparently synchronous with those at the Pinnacles, and thus possibly some of the material may have been contributed by this source. To draw upon more remote sources does not seem warranted. Admittedly, there is a possibility of volcanism having occurred west of the present Santa Lucia Range in the area now submerged beneath the Pacific Ocean; at present, however, this is without evidence for proof or contradiction.

Evidence for rapid deposition of the tuffs from the air in shallow

[4] Philip Andrews, *op. cit.*, p. 16.

[5] *Ibid.*, pp. 13–22.

[6] P. F. Kerr and H. G. Schenck, "Active Thrust-Faults in San Benito County, California," *Bull. Geol. Soc. America*, Vol. 36 (1925), pp. 472–73, 474.

marine waters, that is, deposition almost simultaneous with explosions, in contrast to longer periods of transportation and possibly reworking of older deposits by streams, is found in the sharp depositional contacts (particularly the lower); marked freedom from contamination of minerals commonly found in sediments of the area; and the lack of any definite characters indicating transportation by moving waters.

The stratigraphic position of the vitric tuff is determined by the presence of a *Nonion schencki* fauna in equivalent beds along the strike a short distance west; thus it is assigned to the Delmontian stage of Kleinpell, or to uppermost Miocene.[7]

A lapilli tuff bed, about 25 feet thick, occurs near the top of the Poncho Rico formation in the Salinas Quadrangle is exposed on and near the Laureles Grade, and in the hills southwest of Spreckles; a short distance west of Pine Canyon summit a thin bentonitic clay bed occupies the same stratigraphic position as the lapilli tuff. Post-Poncho Rico erosion has removed the tuff from a large part of the area. Fragments in the bed average 10 mm. in diameter; they are composed chiefly of light-colored rhyolitic material; they are embedded in a clayey matrix which is apparently devitrified volcanic glass. Thin opal bands are present. The evidence for assigning the source of this tuff to the Pinnacles is not as tenable as in the case of the vitric tuff in the Monterey formation. If the Pinnacles can be accepted as the source for the Monterey tuff there does not appear to be immediate reason for not making the same application in this case.

The Poncho Rico rests conformably on the Monterey in the Salinas and Jamesburg quadrangles, with the possible exception of one small area of local discordance. It is disconformably overlain by the Paso Robles terrestrial beds of Upper Pliocene (?)-Pleistocene age. A marine molluscan fauna occurring in a reef near the base of the Poncho Rico formation is that of Miocene-Pliocene transition.[8] The tuff, occurring at the top of this formation, can thus most likely be assigned to lowermost Pliocene age.

The Pinnacles volcanism was predominantly explosive in the terminating phases.[9] In consideration of this fact and the evidence already noted, it is concluded that the Pinnacles volcanic activity continued beyond the previously determined limit of lower Middle

[7] C. L. Herold, "Geology of the Salinas Quadrangle, California," *Proc. Geol. Soc. America, 1935* (1936), pp. 337–38.

[8] C. L. Herold, *op. cit.*

[9] Philip Andrews, *op. cit.*, pp. 15, 23, 31.

Miocene (Temblor) to uppermost Miocene, and possibly into lowermost Pliocene.

The question may arise as to why the earlier phases of the Pinnacles volcanism did not contribute to the earlier sediments in the Salinas-Jamesburg quadrangles. It may be answered in part by one or a combination of the following factors: (a) explosions were chiefly confined to later phases of the activity; (b) size of earlier ejectamenta or lack of sufficient propulsive force may have prohibited transportation over such distances; (c) direction of prevailing winds; (d) directional effects of explosions; (e) possibility of lesser explosions over a longer period of time, thus enabling any volcanic débris that might have been blown to the Santa Lucia Range to be thoroughly distributed and admixed with the granitic detritus of the earlier sediments by wave and current action in the comparatively shallow waters.

Of evidence to further define the beginning date of activity at the Pinnacles, the writer has no knowledge. Careful search in subsequent studies of fossiliferous Miocene and Pliocene sediments in areas less remote than those described above may yield more definite evidence not only for the beginning date, but also for the dying phases of the Pinnacles volcanism.

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June 25, 1937

KNOXVILLE SERIES IN CALIFORNIA MESOZOIC[1]

The Knoxville series, as now known, is typically developed along the eastern foothills of the front mountain range of Klamathonia, that is along the western border of the Sacramento Valley, north-central California. In this zone the series crops out from south of Knoxville, Napa County, northward to, and beyond, the Cold Fork of the Cottonwood Creek, western Tehama County, almost continuously, for a total distance of about 100 miles, its stråta dipping at a high angle toward the east, and passing beneath the floor of the Great Valley.

The maximum thickness of the series is nearly 16,000 feet where it is crossed by the Redbank Creek, but toward the south the thickness diminishes to 14,000 feet near McCarthy Creek, Tehama County, to 12,000 feet in western Glenn County, and to less than 7,000 feet in western Colusa County, and at Knoxville.

[1] Abstract of the article presented before the Association at Los Angeles, March 19, 1937.

In composition and character the series is almost wholly detrital, consisting of a succession of lithologic types, shales, sandy shales, sandstones, conglomerate, and at the top a thick succession of fine shales. These types vary in order and thickness in different sections, due to slight disturbances during deposition, shore conditions, stream discharge, or currents. In its more shaly parts are numerous interpolations, or lenses, of concretionary limestone, many of which are highly fossiliferous, although the shales are generally barren.

In its geological relations the Knoxville series is unconformable with the overlying Shasta series (Lower Cretaceous), and with a succession of older rocks below, including ancient schists, Paleozoic limestones, cherts, and slates that are generally referred to the "Franciscan series," and a variety of basic igneous rocks, greenstones, serpentine, and gabbros. Its basal relations are assumed to be those of local and regional unconformity.

In its type area the Knoxville series is essentially a delta deposit, built up in part about the discharge point of a considerable river system issuing eastward from the ancient land area of Klamathonia. The delta head is found in the topographically low interval between the north flank of the Yolla Bolly Mountains and the south flank of the Bully Choop range, each forming parts of the front range of the Klamath Mountains, as now known. The drift of detrital sediment extended toward the south along the eastern coast line of Klamathonia toward the point of marine entrance into the basin of the Great Valley south of Clear Lake.

For the most part the present structural conditions are simple, forming a steeply dipping monocline inclined toward the east, although in places the strata are much disturbed; south of Knoxville the series is much broken by faulting, and south of San Francisco Bay it is found only in small disconnected areas, as at Mount Diablo, and in the Diablo Range, and near San Luis Obispo, and in the Santa Ynez Range, Santa Barbara County. South of this it has not been recorded.

In southern Oregon near Riddle, Douglas County, at Elk Creek, Curry County, and at other places, the series is represented, but farther north it has not been recognized, although it may occur in British Columbia (Harrison Lake) and in southern Alaska (in the "Kennicott formation").

In its more typical sections in the Sacramento Valley the series is separable into three lithological divisions, lower, middle, and upper, in which the lower and upper divisions are made up of black or dark-colored shales, many of the lower being sandy, or pebbly. The middle

division contains thick beds of conglomerate and sandstone, especially toward the north, near the delta head. It is here overlapped by the Lower Cretaceous Shasta series.

The materials of the conglomerates (and of the other types of sediment) are such as are found in the harder rock masses of the Klamath Mountains, the modern representatives of Klamathonia. Among these are hard siliceous cherts, quartzites, porphyrites, and other classes of igneous and metamorphic rocks.

The known faunas of the Knoxville series have come mainly from the two distinct shale members, both of which yield fossils of late Jurassic age, Portlandian and Tithonian together making up not less than 66 species of marine invertebrates, as follows.

	Number of Species
Ammonoids (*Berriasella, Phylloceras, Perisphinctes, et cetera*)	15
Belemnoids (*Cylindroteuthis, Belemnopsis, Acroteuthis, et cetera*)	17
Pelecypods (*Aucella, Inoceramus, Nucula, Lucina, Opis, et cetera*)	27
Gastropods (*Trochus, Turbo, Itieria, Cerithium, et cetera*)	6
Brachiopods (*Rhynchonella*)	1
Total number known to date	66

The fauna found in the lower shales consists of various species of *Belemnopsis* and some characteristic species of *Aucella*, all of Portlandian aspect; near the top of the series (upper shales) there is a greater variety of types (ammonoids, belemnoids, *Aucellae, et cetera*) all of distinctly Tithonian, or of late Portlandian characters. Less than one-half of the distinctively Knoxville forms have yet been described, although some of them have been listed in earlier papers.

No account has yet been found in the literature describing any body of Jurassic strata in California, or on the Pacific Coast, that is comparable with the Knoxville series in volume and age, as here described, and which constitutes one of the most important units of the geological column, in both volume and time.

A final correlation of the Knoxville series with other stratigraphic units, or with such deposits in other regions, has not been attempted, although its equivalents have been described in part by Diller, Knowlton, and others, including those containing the so-called "Jurassic Flora of Oregon," and probably strata found about Harrison Lake, British Columbia, and perhaps some portion of the "Kennicott formation" in Alaska. In other countries bordering the Pacific its equivalents will be found in the Tithonian deposits of Mexico and Argentina; and in the opposite direction, the "Torinosu series" of Japan appears to include strata correlative with the Knoxville.

FRANK M. ANDERSON

BERKELEY, CALIFORNIA
August 5, 1937

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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DISCUSSION

GEOLOGICAL EXPLORATION BETWEEN UPPER JURUÁ RIVER, BRAZIL, AND MIDDLE UCAYALI RIVER, PERÚ

The paper by Victor Oppenheim "Geological Exploration between Upper Juruá River, Brazil, and Middle Ucayali River, Perú,"[1] is a valuable contribution to a portion of the Upper Amazon region that had been one of its *terrae incognitae*. It extends the eastern limit of Andean structure and geology a considerable distance farther out into the Amazon Basin. The following comments and additions will serve to expand its scope and to point out more fully its relations to other areas of the Upper Amazon region.

The nearest previously described areas are the Pongo de Manseriche[2] and the Pichis and Pachitea rivers,[3] which lie west of the Ucayali River, whereas the region described by Oppenheim extends some distance east of the Ucayali River. The same stratigraphic and structural characters described in the Pongo de Manseriche and along the Pachitea River are shown to extend beyond the boundaries of Peru into the Brazilian Acre.

A generalized correlation of the formations in the three areas is:

Singewald	*Moran and Fyfe*	*Oppenheim*
———	Arcillas Rojas	———
Brown beds	Capas Morenas	———
Red beds	Arenisca de Puca	Cruzeiro Red beds
Huacanqui sandstone	Arenisca de Azucar	Sungarú sandstone
Shale-limestone series	Calizas de Chonta	Shales and limestones
Pongo sandstone	Arenisca de Agua Caliente	Môa sandstone

The age of the Pongo-Agua Caliente-Môa sandstone is fixed by that of underlying and overlying fossiliferous shales and limestones. The underlying limestones are of Jurassic age, and the overlying beds extend down as low as Albian. The Pongo sandstone is Lower Cretaceous, or Neocomian in age, and may extend downward into uppermost Jurassic. In all three regions the upper part is marked by numerous hot springs. In none of the areas described is the base of the formation exposed, but Moran and Fyfe found the underlying limestones about 13 miles east of the Pachitea River on the Rio Yamería. In the Serra do Môa and along the Pachitea River, only the top of the formation is exposed. In the Pongo de Manseriche a thickness of 1,000 feet is exposed. Moran and Fyfe do not state the total thickness of the formation east of the Pachitea River, but they describe horizons of shale in the lower third which are 330–500 feet thick, indicating a total thickness of much more than 1,000 feet.

[1] Victor Oppenheim, "Geological Exploration between Upper Juruá River, Brazil and Middle Ucayali River, Perú," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), pp. 97–110.

[2] Joseph T. Singewald, Jr., "Pongo de Manseriche," *Bull. Geol. Soc. America*, Vol. 38 (1927), pp. 479–92.

[3] ———"Geology of the Pichis and Pachitea Rivers, Perú," *ibid.* (1928), pp. 447–64.

Robert M. Moran and Douglas Fyfe, "Geología de la Región del Bajo Pachitea," *Bol. Official de la Dirección de Minas y Industrias*, Año XII, No. 41 (1933), pp. 43–54.

The Shale-limestone series (Calizas de Chonta) is fossiliferous. The collections by Singewald from the Pongo de Manseriche range from Albian to Coniacian. His collections along the Pachitea River include only Coniacian. Moran and Fyfe's collections, mainly from the same locality, were determined as Coniacian, but include forms that have been correlated as Turonian. Their collections include beds east of the river from probably lower horizons. In the Pongo de Manseriche these beds have a thickness of 3,500 feet. Along the Pachitea more than 500 feet of beds are exposed. Only the upper beds are exposed in the plunging anticline at Baños and the lower beds are faulted out at Isla Chonta. Moran and Fyfe give the total thickness in this area as approximately 1,300 feet. Oppenheim found a thickness of more than 1,000 feet.

Near the top of the Shale-limestone series in the Pongo de Manseriche is a horizon of massive sandstone which Singewald called the Huacanqui sandstone. He applied the same name to a prominent sandstone horizon on the Pachitea River well exposed in the vicinity of Baños. Moran and Fyfe state that they did not encounter the Huacanqui sandstone in the Pachitea River area, but describe sandstone beds 500 feet thick on top of the Shale-limestone series which they consider the base of the Arenisca de Puca and call the Arenisca de Azucar. Their respective geologic maps of the Pachitea River show that Singewald's Huacanqui sandstone on the Pachitea River and Moran and Fyfe's Arenisca de Azucar are the same beds. At Baños the white sandstone is separated from red beds by about 100 feet of lead-gray shale with intercalations of green-gray and blue-gray shale and thin beds of sandstone. For that reason the sandstone was correlated with the Huacanqui sandstone of the Pongo de Manseriche and considered as part of the underlying group of beds. The sandstone is there, and the question raised by Moran and Fyfe is merely whether it and the beds immediately above it should be grouped with the strata below the Red beds or with the Red beds. On a lithologic basis in a rapid reconnaissance, in view of the lithology at the Pongo de Manseriche, the former division seemed the more logical. The more detailed work of Moran and Fyfe may have shown that the latter is a better division. Oppenheim also found a horizon of white sandstones about 500 feet thick between red beds and the Cretaceous shales and limestones which he called the Sungarú sandstone and considered the equivalent of the Huacanqui and the Arenisca de Azucar.

The Red beds at the Pongo de Manseriche appear to have a thickness of at least 4,000 feet. The complete section along the Pachitea and Pichis rivers is estimated by Singewald to have a thickness of 3,000 feet. Moran and Fyfe judge their thickness to be more than 5,000 feet. Oppenheim gives no estimate of their thickness, but their widespread occurrence in a vast area east of the Ucayali River indicates a thickness of the same order of magnitude. The base of the Red beds is Upper Cretaceous, probably beginning about at the top of the Coniacian. The age of the top of the Red beds is more uncertain. They are only sparingly fossiliferous and paleontological evidence is limited. Singewald's collections contained late Cretaceous forms near the base and forms that may be as young as Miocene or Pliocene in the upper beds. In view of the fact that following them and preceding the late Pliocene Pebas beds, there occurred at least the deposition of the more than 3,000 feet of Brown beds and the folding of the Cordillera Oriental Miocene would

seem to be as young as the top of the Red beds could be. Without additional paleontological data, Moran and Fyfe consider them probably of Upper Cretaceous and Lower Tertiary age. Oppenheim found fossiliferous beds at Aquidabam on the Juruá River overlying the Cruzeiro Red beds that were considered late Tertiary, most probably Pliocene, and concluded that the Red beds were late Cretaceous-Middle Tertiary. Oppenheim considers them, therefore, as not younger than Miocene. The Red beds appear, consequently, to include all of the Paleogene and may extend into the Neogene.

In the Pongo de Manseriche area is a younger series of Tertiary beds of considerable thickness that are lithologically unlike the Brown beds of the Pichis-Pachitea region. The Brown beds differ from the Red beds mainly in color, though there are other minor lithologic differences. Three thousand feet of these beds are exposed along the Pichis and Azupizu rivers between the base at Rio Palcazu and Puerto Yessup without including the top. These beds are only mentioned by Moran and Fyfe as they are outside of the area studied by them. They apparently do not occur east of the Pachitea and Ucayali rivers. They are older than the folding that preceded the late Pliocene Pebas beds and are probably mainly Miocene. They may extend into early Pliocene; and, if the top of the Red beds has been placed too young, they may extend into late Oligocene.

Between the Pichis-Pachitea River area and the Serra do Môa is another area of uplift exposing Cretaceous rocks that is unknown in geologic literature. It includes the Sierra de Contamana east of the Ucayali River, between the Ucayali and the Tapiche rivers. This range is described physiographically by Oppenheim, but concerning its geology he merely says that it is a partly monoclinal type of structure with north-south faults, and that, being nearer the main orogenic center of the Andes, it is more intensely folded and fractured than the farther outlying Serra do Môa.

East of Contamana, between the Ucayali River and the Tapiche River, except for the Sierra de Contamana, the terrane is underlain continuously by the Red beds. The Contamana Mountains have a width of about 35 miles. They include two uplifts separated by a Red-bed valley about 7 miles wide. The formations exposed are the Pongo sandstone, the Cretaceous Shale-limestone series, and the Huacanqui sandstone. The western ridge is a sharply folded anticline of Pongo sandstone with a steep westerly dip and a more gentle easterly dip. More than 1,000 feet of Pongo sandstone are exposed. The Shale-limestone series is poorly exposed at its base on the west side and a ridge of low foothills marks the outcrop of the Huacanqui sandstone near its top. The thickness of the series may be as much as 2,000–3,000 feet. On the west side of this ridge the Red beds are faulted against the Pongo sandstone. The eastern ridge is a broad flat uplift underlain by flat-lying beds of Pongo sandstone. At the western base of the ridge the beds are warped downward and overlain by the Shale-limestone series. A prominent foothill ridge marks the position of the Huacanqui sandstone near the top. These beds have a moderate westerly dip. At the eastern base is a zone of gently easterly dipping beds of the Shale-limestone series which is faulted down against the Pongo sandstone on its west side and in fault contact with the Red beds on its east side. The Cretaceous rocks of this ridge occupy an outcrop width of more than 20 miles.

The Sierra de Contamana does not cross the Ucayali River at Cancha-

huaya, as stated by Oppenheim, but a pronounced eastward bend in the river just cuts into the western flank of the range. The Huacanqui sandstone is exposed at the river bank, and then successively inland come the Shale-limestone series and the Pongo sandstone. All have a steep westerly dip. This is the only point along the Ucayali River below the Pachitea River where Cretaceous rocks come to the surface.

The report by A. Cabrera La Rosa mentioned by Oppenheim covers the Santiago River valley northwest of the Pongo de Manseriche[4] and constitutes a connecting link between these Peruvian areas and the Ecuadorean region described by Wasson and Sinclair[5] in which the geology is the same.

In addition to the Red beds (Arenisca de Puca), Moran and Fyfe show on their geologic map an alluviofluvial formation called Arcillas Rojas which they do not discuss in the text and which is not described by Singewald and Oppenheim. This is a distinction well worth making, though at times difficult to apply. Along all of the rivers, where the terrane is flat, outcrops are scattered and small and limited to exposures in the banks of the streams. Where the streams flow through or drain Red-bed terrane, many of these outcrops consist of soft red clays with little or no stratification and without sandy intercalations to indicate bedding. It is difficult to decide whether they represent weathered outcrops of Red-bed shale or whether they represent redeposited Red-bed débris. In many instances, especially downstream where the flow of the rivers is less rapid, they are the latter and should be mapped as Arcillas Rojas and not as Red beds.

JOSEPH T. SINGEWALD, JR.

BALTIMORE, MARYLAND
August 30, 1937

[4] A. Cabrera La Rosa, "Notas sobre la Geografía y Geología del Valle del Rio Santiago," *Rev. Cien.*, Vol. XXV (1932), pp. 397–402.

[5] Theron Wasson and Joseph H. Sinclair, "Geological Explorations East of the Andes in Ecuador," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 1253–81.

SEDIMENTATION IN BARRED BASINS, AND SOURCE ROCKS OF OIL

The writer submits a few corrections to the paper of W. G. Woolnough "Sedimentation in Barred Basins, and Source Rocks of Oil," appearing in the September issue of the *Bulletin*, particularly concerning that part of the paper which quotes Hedberg.[1]

Mr. Woolnough has in some manner inverted the stratigraphic sequence of northwestern Venezuela. Hedberg divided the Cretaceous into an *upper* La Luna limestone series and a *lower* Cogollo limestone series (misspelled Congollo by Woolnough[2] in his quotation). Mr. Woolnough has this sequence reversed in his paper, although the error is obvious in a direct quotation from Hedberg which he uses on page 1138: " . . . the change *from* Congollo *to* La Luna deposition . . . " (italics are Wilson's). Hence Woolnough's hy-

[1] H. D. Hedberg, "Cretaceous Limestones as Petroleum Source Rocks in Northwestern Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 3 (March, 1931), pp. 229–46.

[2] W. G. Woolnouth, "Sedimentation in Barred Basins, and Source Rocks of Oil," *ibid.*, Vol. 21, No. 9 (September, 1937), p. 1137.

pothesis that a barred basin produced La Luna conditions which were eventually dominated by the Cogollo sea is invalid.

Of course, the possibility that the La Luna sediments were accumulated in a barred basin succeeding the Cogollo environment, and in turn succeeded by the Colon shale facies, remains; the writer is not sufficiently acquainted with the area to comment on this aspect of the question. In this connection, Mr. Hedberg's reply[3] to a discussion of his paper by R. A. Liddle is of interest.

> . . . it should be noticed that the same formation [La Luna] in essentially similar development is known in Colombia (the Villeta formation) and in Eastern Venezuela (the Guayuta formation). The distinctive character of the rock is thus not the product of any particular local environment, but is the result of conditions of deposition which must have prevailed during a part of the Cretaceous throughout much of northern South America and possibly neighboring regions for a sufficient length of time to permit the deposition of from 500 to 3,000 feet of limestone.

THOMAS C. WILSON

ZANESVILLE, OHIO
September 19, 1937

[3] H. D. Hedberg, " 'Cretaceous Limestone as a Petroleum Source Rock in Northwestern Venezuela.' Reply to Discussion by R. A. Liddle," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), p. 477.

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REVIEWS AND NEW PUBLICATIONS

Essentials of Engineering Astronomy. By JERRY H. SERVICE. Prentice-Hall, New York (1937). xv + 167 pp., 33 figs. $2.50.

This is a clearly written text offering a combination of theory and practice for the ordinary surveyor. The author says at the outset, "This book is not addressed to geodetic engineers . . . [but] has been written for the reader who has available only a good transit and a good watch."

The introductory chapter, a bit unusual for a book of this type but an excellent thing, is a brief, well written, and remarkably comprehensive description of our solar system and stellar galaxy.

Development of the fundamental formulas relating to the spherical triangle are omitted, but the list of formulas given is adequate and more extensive than in most texts of this type. Actual working formulas for the astronomical triangle (in terms of azimuth, latitude, hour angle, and altitude) are derived from the fundamental formulas when needed.

Part I, on "Fundamentals," besides including the topics mentioned, deals with the theoretical aspects of coördinate systems on the celestial sphere and derives formulas for the usual problems of determination of time, azimuth, latitude, and longitude, and the errors in observed altitudes. Problems of time and longitude are explained only by diagrams that are not easily understood.

Part II has an opening chapter on star identification designed to teach one ignorant of the constellations how to identify the brighter stars whose positions are given in the American Ephemeris. Except for the last three chapters on the striding level, solar attachments, the sextant, determination of position at sea, and the computing machine, this part consists mainly of reproduction of sample records of observations and ruled blank forms showing how to record observations. Twenty-six pages in the book are taken up with this type of illustration.

The book is profusely illustrated with diagrams, only about 100 pages being devoted to reading matter. The major part of the instruction is given by citing special examples rather than by general explanation.

J. O. HASSLER

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NORMAN, OKLAHOMA
July 21, 1937

Natural Gas in Eastern Kentucky. By WILLARD ROUSE JILLSON. 237 pp. Illus. Standard Printing Company, Louisville, Kentucky (1937).

This book was prepared as a companion volume to *Natural Gas in Western Kentucky*, by the same author, but failed of publication by the Kentucky Geological Survey because of abolishment in 1932. It is written primarily for "operators, landowners, and others interested in the natural gas industry in Kentucky." Each field is named and treated separately as to location, development, production, history, ownership, pipe lines, operating companies, markets, geology, and well records. In addition, there is a small sketch map showing the geographical outline and position of each field with pipe lines, limiting wells, and outlying gas wells.

Geological descriptions are mostly concerned with the topography and stratigraphic position of the producing zones rather than the relationship of the reservoirs to structure or detailed descriptions of the structures. However, for many of the fields the author gives a brief description of the surface structure and occasionally of the subsurface. No columnar or stratigraphic sections are presented. From a geological standpoint, it is rather disappointing that all structural maps could not have been assembled to accompany the volume, as the author points out that most of such maps are available, having been issued by the Kentucky Geological Survey from time to time. However, the purpose of the volume would not necessarily include such maps, and the references with scale *et cetera* are clearly set out at the beginning of each field description.

The volume is most interesting from a statistical standpoint, particularly production data pertaining to the fields. The author states that the "Black shale" is the chief gas-producing zone, but does not stress the shooting of this zone, without which, according to other authorities, "the 'Brown shale' of Devonian age would be a non-commercial horizon on the eastern flank of the Cincinnati arch in Kentucky."[1] Reserves are not discussed separately, but in Chapter I a general idea of reserves is given. Gas analyses are treated in the same fashion. A bibliography and index are welcome adjuncts and greatly simplify references to contained data.

The author concludes that "natural gas development in this area will never again equal that of the years of great expansion—1928 to 1930."

To anyone interested in the gas industry of eastern Kentucky this book should be indispensable.

H. C. ARNOLD

TULSA, OKLAHOMA
July 26, 1937

Petroleum Development and Technology—1937. By the Petroleum Division. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 123. 689 pp., illus. Published by the Institute, 29 West 39th Street, New York City. Price, $5.00.

This annual publication for 1937 contains the papers and discussions presented before the Division of Petroleum at Los Angeles, California, October 1 and 2, Fort Worth, Texas, October 8 and 9, 1936, and at New York, February 15–19, 1937. A few papers which have appeared in technical journals are listed by title with reference to the particular publications wherein they may be found. The usual high standard for the material and its presentation has been maintained. Geologists will find papers of particular value according to their present and possible future work in the industry, and also according to their interest in subjects more remotely connected with their duties. The volume stands as a fair record of industrial thought and action during the past year.

Chapter I, "Production Engineering," 6 papers, 54 pages: "Sucker-Rod Pump as a Problem in Elasticity"; "Determination of Fluid Level in Oil Wells by the Pressure-Wave Echo Method"; "Use of Data on the Build-Up of Bottom-Hole Pressures"; "Influence of Production Practices on Gravity of Produced Oil"; "Bibliography on Acid Treatment of Oil Wells"; "Recent

[1] Coleman D. Hunter, "Natural Gas in Eastern Kentucky," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), pp. 915–47.

Developments Related to Petroleum Engineering." Geologists who have been assigned problems in bottom-hole pressure determinations will find interest in the paper on that subject.

Chapter II, "*Production Engineering Research*," 4 papers, 64 pages: "Flow of Gas-Liquid Mixtures through Sands;" "Oil-Well Behavior Based upon Subsurface Pressures and Production Data"; "Productivity Index"; "Experiments on Flow of Fluids through Sands." If one is interested in the behavior of gas-liquid mixtures the first of these papers should not be avoided because of some formidable mathematical equations. The text alone is worth the reading. Bottom-hole pressure studies again appear in this group of papers.

Chapter III, "*Stabilization*," 6 papers, 84 pages: "Can the Rule of Capture be Rationalized?"; "Governmental Regulation of Oil Production"; "Economics and Well Spacing in Texas"; "Acreage and Potential Factors in Allocation"; "Coöperative Development Plan for Buena Vista Hills Oil and Gas Field, Kern County"; "Review of Developments at Kettleman Hills." The first two papers here are of exceptional interest to many geologists.

Chapter IV, "*Petroleum Economics*," 8 papers, 74 pages: "Status and Outlook of Petroleum"; "Chronological Aspects of American Oil-Reserve Replenishment"; "Rôle of Price in the Functioning of Proration"; "Various Aspects of Oil-Stock Prices"; "Future Demand for California Petroleum Products"; "Future Supply of Oil in California"; "Developments in Petroleum Marketing"; "World Consumption of Petroleum Products." The second and third of these papers brings out some logical ideas which are probably new to many geologists. The last of this list contains statistics of general interest.

Chapter V, "*Production*." This chapter contains 30 papers, 262 pages, on domestic production, and 21 papers, 104 pages, on foreign production. Statistics for the most important fields of the world are therein presented. If a geologist feels that he is not up to date in his knowledge of other regions he here has an opportunity of becoming so with little effort.

Chapter VI, "*Petroleum Engineering Education*," 3 papers, 20 pages: "Problems and Objectives of Petroleum Engineering Education"; "Petroleum Engineering Education"; "Combination Field Work and Class Work." Perhaps every petroleum geologist has ideas as to what a petroleum engineer ought to study in college. These papers reveal some of the difficulties encountered in the teaching profession.

Chapter VII, "*Refining*," 1 paper, 4 pages: "Developments in Refinery Engineering in 1936." But few geologists attempt to follow activities in refining.

The present volume and all its predecessors constitute an essential set in the library of active geologists in petroleum.

STANLEY C. HEROLD

LOS ANGELES, CALIFORNIA
September 1, 1937

Geology and Oil Resources of the Bradford Field, Pennsylvania and New York. By CHARLES R. FETTKE, *Pennsylvania Geol. Survey Bull. 116* (May, 1937). 13 pp., 5 maps and pls. Distributed free.

This is a brief preliminary report. The complete report of 600 pages and 40 plates and more than 100 figures should be available late this year.

In 1934 Bradford field ranked eighth among the major oil fields of the United States in total oil produced. It is exceeded in continuous productive area only by the East Texas field. Between 1871 and 1936 it yielded more than 352 million barrels of oil and an ultimate yield of half a billion or more barrels is anticipated. The field has gained added distinction as the "experimental home" of the controlled water-drive method of secondary recovery.

About one-third of the paper is devoted to a description of the geology of the Bradford region, one-third to a discussion of the Bradford Third sand and the Bradford oil pool, and one-third to a quantitative consideration of methods and results of water flooding.

Mention of the stratigraphy, although brief, includes pertinent data on the oil sands of Bradford pool and on their correlation with the sands of adjacent regions. Surface structure is shown by 50-foot contours on the base of Olean conglomerate; subsurface structure by 10-foot contours on the top of Bradford Third sand.

Characteristics of Bradford Third sand are summarized in some detail. Form and limits of the sand body, lateral and vertical variation within it, its petrography, and the probable conditions attending its deposition are discussed. A selected section with porosity and permeability profile of the sand is included.

Stratigraphic and structural influence on accumulation in the Bradford pool is considered briefly; most attention is directed toward a detailed quantitative analysis of the oil content of Bradford Third sand. Probable values for original oil content of sand, oil produced by natural methods, and oil obtained and obtainable by present flooding practice are arrived at.

The pages devoted to methods and results of water flooding are of more than local interest. "Methods" are mentioned very briefly; "results" are presented by tabulating, for 29 specific examples, critical data such as well spacing, sand thickness, pressures, oil recovery, oil-water ratios, *et cetera*. The table serves as the basis for a rather comprehensive discussion of critical factors in water-flood practice.

This paper is designed for the use of the man who is only moderately interested in the geology of the area and in the practice of water flooding. It is essentially an abstract of the much more comprehensive and better illustrated publication that will follow. Bradford field has been the laboratory for experimentation in developing the water-flood method of oil recovery. Dr. Fettke, throughout a period of 10 years, has critically observed and carefully analyzed and recorded that development. His record should be of value wherever water flooding is practiced or contemplated.

STANLEY H. CATHCART

HARRISBURG, PENNSYLVANIA
August, 1937

Der Abbau der Gebirge (The "Down-Building" of Mountains). By ERNST KRAUS. Band 1, *Der alpine Bauplan*. 352 pp., 8 structure sections, a tectonic map, 57 text figures. Gebrüder Borntraeger (Berlin, 1936). Price: RM 30; cloth, RM 32.20.

As commonly used, the word "Abbau" means "denudation," but Professor Kraus takes it in a double sense. Remotely, he intends to suggest the ordinary meaning but more directly he refers to the fact that, in his opinion,

mountain structure is formed deep below the surface during a process that involves sinking of a belt of the earth's crust and downward flow of subcrustal matter.

Three concepts, according to Professor Kraus, must be understood and appreciated by anyone who would comprehend the genesis of the Alps.

First, each section across the range shows two Narben ("scars") or Scheiteln ("partings"). These may be recognized as the belts or lines toward which, in general, strata, nappes, and thrusts all dip from both sides. Since there are two of these partings on each Alpine cross section, the Alps are not—as most geologists suppose—a single "orogen" but a double "orogen." Second, these partings are not zones of roots, but belts of sinking, where downward currents of magma have been active and have dragged in and partly engulfed sheets of rock from adjacent areas. This interpretation is said to be corroborated by the fact that the partings have, in general, masses of young rocks along them, instead of old rocks, as a zone of roots should have. Thus, the nappes have not risen from the belts of "parting," but have been dragged toward and into them from the sides.

Third, and of most fundamental importance, the cause of mountain-building, as previous paragraphs have already indicated, is subcrustal flowage. The partings, being belts of downflow, are zones of negative gravity anomalies, because of the masses of light rock that have been pressed down into the crust. The downward current causes an inflow of magma from the sides, which drags along the crustal material above it, and piles up as nappes the sheets of cooler material nearest the surface.

Many features of Professor Kraus' orogenic theory are excellently illustrated in his Figure 53, a diagram showing the four stages of the orogenic cycle: (1) the pre-orogenic geosynclinal stage, with sinking salsima beneath the geosyncline and a correlated rise and inward movement of the bordering continental masses; (2) the hyporogenic stage, with differentiation of the salsima, folding of the geosynclinal sediments and of an upper shell of the underlying salsima, with ophiolitic intrusions into both and into the margins of the basin; (3) the epiorogenic (not epeirogenic) stage, with isostatic rise of the central folded mass of geosynclinal materials, foredeep formation along the inner margins of the bounding continental areas, and the beginning of molasse deposition in the foredeeps; and (4) the post-orogenic stage, with sal and sima quiescent, foredeeps filling up, and the isostatically raised mountain mass undergoing erosional denudation.

Another exceptionally interesting feature of Professor Kraus' book is the series of 8 structure sections, partly colored, scale 1:300,000, across the Alps. The first one runs from Bas-Dauphiné to Turin, the eighth from the south margin of the Bohemian mass southwesterly to a point near the north edge of the folded belt along the upper Save. The others are spaced fairly evenly between these two. The greater part of the text (pages 5 to 291) is given over to a description and interpretation of the geology along the lines of these sections. The tectonic map, also partly colored, illustrates the areal relations of the major features displayed in the sections.

The Kraus concept of orogeny owes much, as the author states, to Ampferer and Schwinner, and also has resemblances to the "buckling hypothesis" of Vening Meinesz and the "undation theory" of van Bemmelen. Many other geologists have invoked the aid of subcrustal magma transfer in their at-

tempts to explain mountain building. The volume under review constitutes an elaborate attempt to bring the phenomena of the Alps into harmony with the Kraus version of this theory. Of the success of the attempt, only geologists thoroughly familiar with Alpine geography and geology might hope to judge. In future volumes the author plans to develop the theory in relation to some other mountains of the world; a procedure that may better enable non-Alpine geologists to judge of its merits.

In his choice of terms Professor Kraus does to some extent what geologists often recommend to one another—he replaces technical terms like "paläogeographisch" by non-technical terms, like "vorzeiterdkundlich." Even though the less technical terms are occasionally followed parenthetically by their technical equivalents, the results of the attempt, so far as foreign readers are concerned, are simply to give his text a strange appearance and make it a little less easy to read.

R. D. REED

LOS ANGELES, CALIFORNIA
August 23, 1937

Geotektonische Forschungen. Edited by H. STILLE and FR. LOTZE. No. 1: "Zur germanotypen Tektonik I" (Geotectonic Research. No. 1: German Type Tectonics I). By H. STILLE, FR. LOTZE, E. LEMKE, H. J. MARTINI. 123 pp., 78 figs., 8 pls. Gebrüder Borntraeger (1937). Subscription price: if No. 1 and 3 subsequent numbers are ordered, RM 6.70 each. Foreign discount.

This book is the first of a series of monographs on structural topics by members of Professor Stille's able school of geologists. Preceded by two brief introductory chapters by Stille and Fr. Lotze, this volume presents detailed descriptions and discussions of two disturbed belts within the large Permian-Mesozoic area that lies east and northeast of the Rhenish Slate Mountains. The peculiar fault zones, folds, upthrusts, and graben structures of this area, due, in part, to "salt tectonics," have been discussed in several articles in this *Bulletin*. The structural features of this part of Germany are of special significance in view of the similar problems in other regions where salt-bearing formations are assumed, or known, to occur.

In the paper, "Structure of the Area between Vogelsberg and Rhön," E. Lemke discusses the structural geology of an area of about 1,250 square miles, located about 65 miles northeast of Frankfort-on-the-Main. Detailed work covers selected areas aggregating some 154 square miles. The flat Mesozoic strata are here traversed by a discontinuous, disturbed, *en échelon* belt of graben structures, trending northwest and southeast, about 25 miles long, and 2 miles wide. In plan, the belt is slightly arcuate, convex toward the southwest. Perpendicular to the arc, other graben and fracture belts strike northeast and southwest, the easternmost striking more nearly north-northeast and south-southwest.

Two stages in the development of the graben structures (in late Jurassic time) are recognized. During the earlier one, the belts were dropped along normal faults, due to crustal distension. In the second stage, however, the northwest striking troughs, in contrast to the others, have been compressed, whereby the internal structure of this group has been modified. Thus, marginal and internal normal faults which dipped toward the graben were bent

and steepened, especially along the northeast border, and from here the surrounding Triassic rocks have been thrust over the graben rim, along northeastward dipping reverse faults. Overthrusts on a smaller scale occur within the graben, especially along the borders of local horsts that split the graben into several troughs.

The second paper, "Crustal Blocks and Graben Structures between Habichtswald and Rhenish Slate Mountains," by H. J. Martini, describes similar structures in an area about 50 miles north-northwest of the former. This district lies closer to the eastern border of the Slate Mountains, and where graben zones of west-northwesterly strike, like the large Kassel graben, approach the old mountain mass, they bend through northwest-southeast to north-northwest directions. In this border zone faults and graben zones of north-northeast strike transect the other dislocations, causing structural complications of considerable complexity. Martini holds, as does Lemke, that graben zones of northeast, or north-northeast, strike have developed as, and remained, purely distensional structures, whereas the northwest trending zones have been laterally compressed during a later stage. The following facts support this view. 1. The Mesozoic strata within the northwest striking zones are commonly folded, and overturned southwest; the northeast border of a graben tends to override the graben. 2. The north-northeast striking graben zones have been distended up to 645 feet, but show greater downthrow (up to 1,200 feet), and no internal folds; whereas the northwest striking Kassel graben has a maximum downthrow of 2,600 feet, and a maximum shortening of 3,570 feet. 3. In another graben system, trending north-northwest, the distension just about equals the downdrop, and there is no evidence of appreciable lateral compression. 4. Fractures striking northeast or north-northeast, have remained open, like tension joints, whereas other systems striking more or less perpendicular to this, have been closed after an initial period of gaping.

Elements of special interest are horsts of soft gypsiferous Triassic beds within the Kassel graben, the tops of which bend outward over adjacent portions of the graben, along several reverse faults that dip into the horst. The extent to which Permian salt below the Triassic strata may have guided the movements in the entire region, is not exactly known, nor is it clear why, during the first deformational stage, graben zones in the northwest-southeast could open. At one point along the northeast border of the Kassel graben salt does break to the surface, rising at least 1,800 feet, but in general the authors do not consider salt tectonics of prime importance in their respective areas.

A wealth of field observations is presented in 58 text figures and 8 plates, consisting of colored areal maps, 70 cross sections, structure maps of individual outcrops, and fault and joint maps (one author has measured 4,200 joints in an area of about 50 square miles). Many other structural problems are dealt with, for example, time relations between the various groups of faults of different strike; the relations between local joint systems, and faults; the degree to which folds indicate horizontal shortening, or downward sagging of blocks; quantitative relations between distension, lowering, and compression of graben zones; the posthumous deformation of the region, with special reference to fractures filled by post-Oligocene basalts, and others. Although the text could probably have been condensed considerably, the style is

relatively easy. Foreign readers will do well to remember, however, that German writers commonly substitute names of mountain ranges for geographic directions. For instance, the terms, "erzgebirgisch," "variszisch," "antihercynisch," and "antieggisch," all mean, essentially northeast-southwest; "hercynisch" and "eggisch" mean northwest-southeast and north-northwest-south-southeast, respectively; "rheinisch" means north-northeast-south-southwest. The use of the term, steep ("steil"), for north-south strike, and of the term, flat ("flach"), for east-west strike, is confusing, and the use of the word, "decke," for a thrust slice, 336 feet wide, seems inadvisable.

The manner in which normal and reverse faults, as well as folds, accompany the borders of the sunken graben zones, resembles strikingly the similar structures along the borders of many western United States uplifts; the transverse normal faults in one graben (pp. 86–87) have their analogs in the familiar cross-faults of several Wyoming and California oil domes, and are interpreted in the same manner. Numerous folds within another graben have their axes at an acute angle to the strike of the graben, reminding one of Coast Range folds, on a diminutive scale.

The methods of work employed by the authors in dealing with a multitude of structural problems, will stimulate and appeal to many readers. This first memoir sets a high standard for the subsequent issues in the series, and students of structural problems may look forward to them with eagerness.

R. BALK

MOUNT HOLYOKE COLLEGE
SOUTH HADLEY, MASSACHUSETTS
September 6, 1937

The Geology of Texas. Volume III. "Upper Paleozoic Ammonites in Texas." By F. B. PLUMMER and GAYLE SCOTT. "Permian Fusulinidae of Texas." By CARL O. DUNBAR and JOHN W. SKINNER. 825 pp., 97 figs., 81 pls. *Univ. Texas Bull. 3701* (July, 1937). Bureau of Economic Geology, Austin. Price, cloth, $4.00.

This publication is the third volume of a series being issued by the Bureau of Economic Geology on the geology of Texas. The first volume, "Stratigraphy of Texas," was published in 1933; the second volume, "Structural and Economic Geology of Texas," was published in 1935. Other volumes in this series will be published in the future. Volume IV, now in preparation, treats of the "Petroleum Resources of Texas."

The present volume is in two parts, as follows: Part 1, Ammonites of the Late Paleozoic of Texas; and Part 2, Permian Fusulinidae of Texas.

Part 1, by Plummer and Scott, is an exhaustive monograph on the ammonites of the Mississippian, Pennsylvanian, and Permian of Texas. The previous work on these ammonites is evaluated, the method of description is given in detail, a chapter on classification is included, and the various zones are worked out for the sections in various parts of Texas, including the north-central Texas area, the Marathon area, and the Delaware and Guadalupe Mountain area.

Three hundred and thirty pages, 71 figures, and 41 plates are devoted to the description of Texas Carboniferous ammonites. This includes 7 clans, 28 families, 70 genera, and 139 species.

The systematic description is followed by a section on correlation of Texas formations by means of ammonites, in which the relative value of the various ammonites as zone markers is discussed, and the importance of using assemblages rather than individuals for the correlation of zones is stressed. Of the larger fossils, ammonites are the best and the easiest to use for zoning the Carboniferous because of their rapid evolution and consequently short range for most species.

Finally 94 ammonites localities of the state are listed, and a bibliography of 268 works on ammonites is given.

Part 2, by Dunbar and Skinner, is an equally exhaustive monograph on the Permian Fusulinidae of Texas. A thorough discussion of how to measure and record shell features is given in which it is stressed that a uniform method of recording these features should be followed. A chapter is devoted to the morphology of the shell wall and another to the synopsis of the subfamilies and genera of the Fusulinidae, which is probably the only complete synopsis under one cover.

The systematic description of Texas Fusulinidae is accomplished in 103 pages of text and 40 plates and covers 11 genera and 57 species. Following this is a check list covering the 38 genera and 540 species described from all over the world up to the time this work went to press. Two hundred and ten fossil localities are listed, and an approximately complete bibliography of 176 works containing either descriptive or taxonomic discussions is given.

The value of the Fusulinidae for correlation purposes in the Permian is probably unsurpassed by any other group. These forms evolved rapidly and consequently are excellent for zoning purposes and, furthermore, are small and numerous, making them excellent for subsurface correlation in borings.

This publication, like the preceding volumes of this series, shows excellent press work. The plates illustrating the fossils are all of the highest grade heliotype engraving. The paper used in the text, although of excellent quality, is light weight, English finish book paper 40, so that the volume, although containing over 800 pages in addition to the plates, is not bulky.

Aid in the completion of this volume is acknowledged in the preface by E. H. Sellards, director of the Bureau, to several sources. In connection with Group Study to Establish More Satisfactory Criteria for the Stratigraphic Correlation of Mississippian, Pennsylvanian, and Permian Sediments in the Texas Region, a contribution was made by the Geological Society of America from the Penrose Fund to The University of Texas, Grant 44–33, a part of which has been applied toward the completion of the memoir on ammonites. In 1930 there was established at The University of Texas, through donation by William F. Morse and others, the Paul Franklin Morse Memorial Publication Fund, honoring the memory of Paul Franklin Morse. The cost of engraving the plates of the memoir on fusulinids has been paid from this fund.

This volume should be a welcome addition to the library of every geologist and paleontologist working in the Carboniferous of America as well as to those interested in world-wide correlations.

V. E. BARNES

AUSTIN, TEXAS
August 9, 1937

RECENT PUBLICATIONS

ARGENTINA

*"Algunas observaciones preliminares sobre los 'Estratos de Malargüe' " (Notes on Malargue Beds), by Paulina Mühlmann. *Bol. de Inform. Petroleras* (Buenos Aires, May, 1937), pp. 43–56; index map, 7 photographs including 6 photomicrographs, and folded correlation table.

*"Las investigaciones geológicas de Y.P.F. en la Provincia de Mendoza y algunos problemas de estratigrafía regional" (Geological Research of the "Government Oil Fields" in Mendoza Province and Problems of Regional Stratigraphy), by Enrique Fossa-Mancini. *Bol. Inform. Petrol.* (Buenos Aires), Vol. 14, No. 154 (June, 1937), pp. 51–118; 18 figs.

ARKANSAS

"Fossil Flora of the Wedington Sandstone Member of the Fayetteville Shale," by David White. *U. S. Geol. Survey Prof. Paper 186-B* (1937), pp. 13–41, Pls. 4–9. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.10.

BRAZIL

* "Trabalhos geophysicos Applicações dos Methodos electricos" (Applied Electrical Methods), by Mark C. Malamphy, H. Capper A. de Souza, Irnack C. do Amaral, and Decio S. Oddone. *Servico Geol. Min. Bol. 81* (Rio de Janeiro, 1937). 51 pp., 31 figs.

CUBA

"Nuevas especies de foraminiferos del Eocene de Cuba" (New Species of Foraminifera of the Eocene of Cuba), by Pedro J. Bermúdez. *Memorias de la Sociedad Cubana de Historia Natural*, Vol. 11, No. 3 (University of Havana, July 10, 1937), pp. 137–50; 4 pls. of fossils.

"Estudio micropaleontologico de dos formaciones Eocenicas de las Cercanias de la Habana," by Pedro J. Bermúdez. *Ibid.*, pp. 153–80.

EAST INDIES

* "The Negative Isostatic Anomalies in the East Indies (with Experiments)," by Ph. H. Kuenen. *Leidsche Geol. Mededeelingen*, Deel 8, Aflevering 2 (Rijksmuseum van Geologie en Mineralogie, Leiden, Holland, June, 1937), pp. 169–214; 24 figs.

ENGLAND

* "The Carboniferous Limestone (Avonian) Rocks of the Bristol Coalfield," by S. H. Reynolds. *Proc. Geol. Assoc.*, Vol. 48, Pt. 2 (London, July 29, 1937), pp. 115–30; 1 pl.

* "The Lower Lias of South Nottinghamshire," by P. E. Kent. *Ibid.*, pp. 163–74; 1 fig.

* "The Occurrence of Nummulites planulatus in England, with a Revised Correlation of the Strata Containing It," by Arthur Wrigley and Arthur G. Davis. *Ibid.*, pp. 201–28; 3 figs., 2 pls. Contains correlation chart of Eocene and Oligocene strata of Anglo-Franco-Belgian basins.

GENERAL

Petroleum Technology in 1936. A comprehensive review of recent developments containing more than 2,200 references to publications on petroleum and cognate subjects. 326 pp., 8 illus. Among the 25 articles the following may be mentioned. "Geology of Petroleum," by G. D. Hobson, 7 pp.; "Regional Geology and Development," by S. E. Coomber, 10 pp.; "Geophysics," by H. Shaw, 13 pp.; "Production," by L. V. W. Clark, 11 pp.; "Drilling," by L. V. W. Clark, 8 pp.; "Petroleum Literature," by Winifred S. E. Clark, 14 pp.; "Petroleum Statistics," by S. J. Astbury, 10 pp. Published by the Institution of Petroleum Technologists, Aldine House, Bedford Street, Strand, London, W.C. 2. Price, clothbound, postfree, 7s. 6d.

"Additions to Some Fossil Floras of the Western United States," by R. W. Brown. *U. S. Geol. Survey Prof. Paper 186-J* (1937), pp. 163–206; Pls. 45–63. Supt. Documents, Govt. Printing Office, Washington, D.C. Price, $0.20.

GEOPHYSICS

* "Some Graphical Solutions in Torsion-Balance Prospecting," by V. Gavrilovich Gabriel. Reprint from *Beiträge zur angewandten Geophysik* (Berlin), Bd. 7, Heft 1 (1937), pp. 39–48; 2 figs.

"Geophysical Abstracts 87, July–December, 1936," by W. Ayvazoglou. *U. S. Geol. Survey Bull. 887* (1937). 98 pp. Supt. Documents, Govt. Printing Office, Washington, D.C. Price, $0.15.

MINNESOTA

* "Geology of Western Minnesota: Traverse, Bigstone Counties," by George A. Thiel. *Oil and Gas Jour.* (August 19, 1937), pp. 26–27; 1 fig.

PATAGONIA

* "Upper Cretaceous Plants from Patagonia," by Edward W. Berry. *Science* (Lancaster, Pennsylvania), Vol. 86, No. 2227 (September 3, 1937), pp. 221–22.

PENNSYLVANIA

* "Subsurface Waters of the Bradford Field," by Charles E. Fettke. *Oil and Gas Jour.* (Tulsa, August 12, 1937), pp. 49–53.

* "Mechanics of Water-Flooding; Evolution of the Practice in Bradford." *Ibid.* (August 19, 1937), pp. 32–36; 2 figs.

* "Relation of Production of Oil by Water-Flooding to the Physical Characteristics of Sand." *Ibid.* (August 26, 1937), pp. 48–50.

TEXAS

* *Oil Weekly* (Houston, August 30, 1937). South Texas Number. Contains folded insert map, in colors, of Rio Grande Embayment, South Texas and Northeast Mexico, showing oil and gas fields and prospective territory. The base map was prepared for the Darby Petroleum Corporation by Harry H. Nowlan and Rae Preece.

"A Redescription of Ferdinand Roemer's Paleozoic Types from Texas," by Josiah Bridge and George H. Girty. *U. S. Geol. Survey Prof. Paper 186-M* (1937), pp. 239–71, Pls. 66–70. Supt. Documents, Govt. Printing Office, Washington, D.C. Price, $0.10.

TURKEY

* "Turkey and Petroleum," by C. E. Tashman. *Maden Tetkik ve Arama*, Enstitüsü Yayimi (Ankara, Turkey), Sene 2, Sayi 3 (Temmuz, 1937), pp. 13–15. Summary of geological investigations and drilling activity for oil from 1897 to 1936.

VENEZUELA

* "El Petroleo en Venezuela" (Petroleum in Venezuela), by Enrique Leupold. *Bol. Inform. Petrol.* (Buenos Aires), Vol. 14, No. 154 (June, 1937), pp. 9–50, illus.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

* *Journal of Paleontology* (Tulsa, Oklahoma), Vol. 11, No. 6 (September, 1937).

"Gastropods of the Family Epitoniidae from Mesozoic and Cenozoic Rocks of the West Coast of North America, Including One New Species by F. E. Turner and One by R. A. Bramkamp," by J. Wyatt Durham.

"Eocene Species of the Genera *Bulimina* and *Buliminella* from Cuba," by F. L. Parker and P. J. Bermudez.

"The *Lepidocyclina texana* Horizon in the *Heterostegina* Zone, Upper Oligocene, of Texas and Louisiana," by Donald W. Gravell and Marcus A. Hanna.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 10 (OCTOBER, 1937), PP. 1364-1367

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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SEVENTEENTH INTERNATIONAL GEOLOGICAL CONGRESS MOSCOW, JULY–AUGUST, 1937

(A LETTER FROM AN ASSOCIATION DELEGATE)

Baku, August 9, 1937

Dear ————

We have just reached here, for a week of geologizing, after 10 solid days of touring in a 7-car special train. The meeting in Moscow was splendid. I have written most of the story and sent a file of the Moscow *News* (English edition) telling about the Congress and giving some of the papers. It is a long story and I will have to wait until I return for the details as we are kept too busy for much writing.

During the Congress in Moscow we made a 2-day excursion, with sleeper jumps, to Leningrad, where Bill Wrather joined the party. After the Congress, 56 of us, including 10 Americans, left on a special train of 5 sleeping cars, one diner, and another car with a shower bath, which will be our home for 32 days, except for 6 in this excellent hotel. We went north and east to Perm, where they have some Permian lime oil; to Swerdlovsk, in the heart of the Urals; to Chelyabinsk, which is just over the line in Siberia; Ishimbayers, with a large new field in Permian lime; Syzran, on the Volga; then southwest to Rostov and southeast to Baku, where we have been just one hour—so you see that I am a faithful reporter.

The trip is nicely interspersed with diversifications so that there is no monotony of geology. We have had a 4-hour trip by boat on the Volga, an auto tour of Rostov-on-the-Den, near the Sea of Azov, and a whole day at Kislovodsk with its remarkable mineral springs, where we all had a bath (much needed) in Harzan—their White Rock. It is a beautiful place full of sanitoriums for heart trouble or nervous break-downs, and I—threatened with both—could have enjoyed a week there.

Every so often the local authorities have a "Reception" for us, an elegant banquet from caviar to champagne (Russian), and some talks of their ideals and progress, and responses with our thanks. The Russians are thoroughly friendly and enormously hospitable, so much so that I understand the "regulars" of other congresses, who have been their hosts elsewhere, are not a little embarrassed thereby.

Everywhere we go, a remote oil-field camp, or the headquarters of some province's Soviet, or a museum, we are welcomed by banners, always in English, usually in Russian also, and sometimes in French. Also there is usually a more or less complete (and mostly *more*) museum of all their specimens of rocks, fossils, and what-not. The height of hospitality came at Syzran, where the visitors expressed special interest in certain cores *et cetera*, and the Russians took a hammer to their nicely polished exhibits, broke them into pieces, and distributed them! This generosity was nearly equalled the day before at Ishimbayero, where Bill Wrather inquired if he might get a list of the fossils in their basal Permian, and samples. They assured him he could, and delivered to him at the train, boxed for shipping, a complete set of their *slides!*

I must not fail to mention that almost without exception the maps, charts, cross sections, diagrams, and graphs—not only in Moscow, but also in the remote provinces—are explained (printed) in Russian *and English.* All talks are also interpreted in English and usually in French, too. We are really impressed by the arrangements which have been made for the Congress and for these excursions.

Best regards,

(*Signed*) J. Elmer Thomas

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Memorial

PAUL VERE ROUNDY

(1884–1937)

Paul Vere Roundy, geologist in the United States Geological Survey, died at his home in Washington, D. C., on June 21, 1937, after many months of illness. Although his condition was known to be precarious, it seemed to be on the mend, and death came very suddenly while he was preparing to go to his office in the morning. He is survived by two sons, Paul V. Roundy, Jr., and Willard H. Roundy, having lost his wife in 1931.

Roundy was born in Cooperstown Junction, Otsego County, New York, on January 8, 1884. After graduating from the Oneonta High School, he attended Syracuse University for two years, but upon receiving an appointment to the Geological Survey in 1908, he moved to Washington and completed his collegiate work at George Washington University, majoring in geology and paleontology. He received his Bachelor's degree from there in 1912.

He was continuously engaged in geological and paleontological work for the Survey from his appointment in 1912 to his death in 1937. His experience covered a wide field somewhat as follows: paleontological work in Virginia, West Virginia, Maryland, and Ohio from 1909 to 1911; areal geology in Utah in 1912; paleontological and stratigraphic work in Arkansas and Oklahoma in 1913; areal geology in Idaho and Wyoming in 1914–1916; oil and gas work in Kansas, Oklahoma, and Texas in 1917–1919. During the years of the World War, he was associated with others in surveying the Osage County oil field of Oklahoma. Ten years later he was one of several detailed to survey the disputed Elk Hills Naval Reserve No. 1 in California.

Much of his published work was in collaboration with others and was in the field of stratigraphy and economic geology, and at the time of his death he had just completed a long report on the phosphate reserves of Florida. Nevertheless, his main interest was paleontology, and during the last decade or so he turned his attention to the field of micropaleontology. He published several papers in that field, but much of his time not otherwise occupied was addressed to laying the foundation for scholarly work on the ostracodes, foraminifera, and conodonts, the fruition of which was cut short by his untimely death. To this end he had made considerable progress, cataloging the genera and species of those groups, and he had in hand several reports, none of which is quite complete.

Roundy was a fine friend and a devoted father. His outstanding trait, probably, was generosity. He was prodigal not only with material things, but with his time and sympathy, and undoubtedly he reduced his own accomplishment by aiding others.

He was a member of the American Association of Petroleum Geologists, the Paleontological Society of America, the Geological Society of Washington, and the Society of Economic Paleontologists and Mineralogists.

BIBLIOGRAPHY OF PAUL VERE ROUNDY

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PAUL VERE ROUNDY

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GEORGE H. GIRTY

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON, D. C.
August 16, 1937

JOHN MANDEVILLE ALDEN
(1888–1937)

John M. Alden died at his home in Tulsa, Oklahoma, August 16, 1937, following an illness of several months. Alden was supervisor of oil and gas operations of the Mid-Continent district for the Oil and Gas Leasing Division of the United States Geological Survey. Through a staff of petroleum engineers, accountants, field engineers, and several district offices he directed operations for oil and gas on the public domain and on restricted Indian lands in Oklahoma, Kansas, New Mexico, Arkansas, Louisiana, Mississippi, Alabama, and Texas.

Alden had numerous interests outside his official duties. He was a past-president of the Kiwanis Club of Taft, California, and a past-director of the Kiwanis Club at Muskogee, Oklahoma. He was active in the Boy Scouts of America in California and later in Oklahoma. He was a member of the Tulsa chapter of the American Petroleum Institute, the Tulsa Geological Society, the American Association of Petroleum Geologists, the College Hill Presbyterian Church, and the Oakhurst Country Club of Tulsa, Oklahoma. Until a few months before his death he was a member of the American Institute of Mining and Metallurgical Engineers.

John Alden was of the ninth generation of the direct descendants of one of America's best known families. John and Priscilla Alden, two young members of Plymouth Colony and earlier both passengers on the Mayflower,

were the founders of the family in America. The story of the courtship of these two early Americans was eloquently told in verse by Henry W. Longfellow in "The Courtship of Miles Standish." The descendants of the famous Colonial couple lived in Massachusetts until 1799, when a member of the sixth generation, who was the great great grandfather of John Alden of Tulsa,

JOHN MANDEVILLE ALDEN

removed to Pennsylvania. John was born the fourth and youngest child of Philo Elzer and Susan Ormsby Alden at Monroeton, Pennsylvania, May 10, 1888. He was christened John Mandeville Alden.

He was educated in his native state of Pennsylvania and as a young man chose to follow his father's occupation of civil engineering. He had his field training in engineering under his father's instruction and later father and son became partners in business. While still a young man John accepted the position of resident engineer for the Coal and Coke Railroad, which position

he held during the construction of the railroad through West Virginia. It was no doubt the careful training of his father and the experience in precision work gained in his railroad engineering in early life that developed the ability for thoroughness which in later years he so completely possessed and which he required of his subordinates.

Following his railroad engineering work Alden was associated for a brief time with a firm of consulting engineers at Clarksburg, West Virginia. In 1909 he was employed as an engineer by the Hope Natural Gas Company, a subsidiary of the Standard Oil Company of New Jersey. He and Hattie Pierson of Gassaway, West Virginia, were married February 21, 1910, and they made their home in Clarksburg. Alden remained at Clarksburg with the Hope Natural Gas Company until 1921, when he joined the United States Bureau of Mines as associate natural gas engineer in the Oil Leasing Division. He was assigned to the Rocky Mountain region and remained there 4 years, making his home and headquarters at Denver, Colorado. Alden joined the staff of the United States Geological Survey July 1, 1925, on which date the Oil Leasing Division of the Bureau of Mines was transferred to that bureau. His advancement was rapid and in 1924 he was transferred to Taft, California, as deputy supervisor of oil and gas operations on the Pacific coast. In 1930 Alden was made supervisor of the Mid-Continent district with headquarters at Muskogee, Oklahoma. Two years later the supervisor's office was moved to Tulsa, where he served until his death.

His passing away has deprived the Geological Survey of an executive with able administrative judgment, his family of a devoted husband and father, and his friends of a true, respected companion. Although quiet and reserved, John had an infinite capacity for making friends and his home was one in which it was always a pleasure to be a guest. His was a pleasing personality. He was dignified in appearance but had a winning smile and a keen sense of humor. He was well read in the current happenings of the world and was, therefore, a pleasing conversationalist but was in no sense garrulous. In his work he was orderly, exacting, and thorough.

Alden is survived by his widow; two daughters, Roberta Priscilla, who is a teacher in the Tulsa schools, and Jean, who is a sophomore at Central High School; and one son, George, who is following in his father's footsteps professionally and is a student in petroleum engineering at Tulsa University.

N. W. BASS

TULSA, OKLAHOMA
September 22, 1937

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 10 (OCTOBER, 1937), PP. 1373-1376

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Society of Economic Geologists will hold its annual meeting in Washington, D. C., at the time of the Geological Society of America meeting, December 28–30.

L. D. BURLING, formerly assistant geologist of the United States Geological Survey, a member of the faculty of Vassar College, and more recently in the employ of oil companies in the Mid-Continent, is going to the University of North Carolina, at Chapel Hill, as associate professor, taking the place of associate professor GERALD B. MACCARTHY while he is on leave.

WILBER H. YOUNG, JR., formerly manager of the Oil Core Testing Laboratory, Inc., at Titusville, Pennsylvania, is now geologist and petroleum engineer for the Empire Gas and Fuel Company at Wellsville, New York.

JULES BRAUNSTEIN has been employed as micropaleontologist by the Shell Petroleum Corporation at Houston, Texas.

JAMES B. TEMPLETON, geologist and land man for the Deep Rock Oil Company at Shreveport, Louisiana, has been transferred to Wichita, Kansas.

C. N. VALERIUS has been transferred from Tulsa, Oklahoma, to Shreveport, Louisiana, as district land man for the Barnsdall Oil Company. His address is 607 Giddens Lane Building.

BOB HANCOCK, formerly with the Indian Territory Illuminating Oil Company, at Bartlesville, Oklahoma, is now with the Magnolia Petroleum Company, at Oklahoma City.

MEREDITH E. JOHNSON, formerly assistant geologist, has succeeded HENRY B. KUMMEL as State geologist of New Jersey. Kummel retires after a service of more than 40 years.

W. R. CHEDSEY has been appointed director of the Missouri School of Mines and Metallurgy at Rolla, Missouri. Chedsey was professor of mining at the School of Mineral Industires at Pennsylvania State College for 21 years.

FREDERIC B. LOOMIS, professor of geology at Amherst College, died while in Alaska last July.

RALPH B. ROARK, manager of production for the Shell Petroleum Corporation, at Tulsa, has been promoted to be vice-president in the Mid-Continent area.

T. E. SWIGART, vice-president of the Shell Petroleum Corporation in the Gulf Coast district, has been transferred to the executive offices at St. Louis.

The members of the permanent council of the World Petroleum Congress appointed since the second congress, June 14–16, in Paris, one of whose duties is to select the meeting place for the third congress, are the following: presi-

dent, Louis Pineau (France), Max Streintz (Austria), Paul Erculisse (Belgium), Charles Bihoreau (France), S. Scheer (France), L. Ubbelohde (Germany), S. J. M. Auld (Great Britain), T. Dewhurst (Great Britain), J. H. C. de Brey (Holland), Stanislas Pilat (Poland), L. Mrazec (Roumania), Gustav Egloff (United States), W. P. Haynes (United States), and secretary, J. Filhol (France).

Mr. and Mrs. PAUL E. FITZGERALD are the parents of a baby daughter, Julia Anne, born at St. Johns Hospital, Tulsa, August 30. Fitzgerald is geologist for Dowell Incorporated.

Data on more than 15,000 genera and species of *Foraminifera*, including 45,000 illustrations, are to be available for the information of geologists, engineers, and other scientists as a result of work now being done by the Geological Research Project of the Works Progress Administration in New York City. Substantial progress toward the completion of the gigantic task of assembling this material has been reported to the Washington, D. C., office of the Division of Women's and Professional Projects of the Works Progress Administration. Ellen S. Woodward, assistant WPA administrator, is director of this division. The finished work is to consist of 25 volumes of about 1,000 pages each, containing in all approximately 45,000 illustrations and bound in loose-leaf form to include supplementary material. BROOKS F. ELLIS, geologist of New York University began this task more than 10 years ago.

F. E. MARSHALL, geologist for Snowden and McSweeney, Incorporated, Wichita, Kansas, has moved to Bridgeport, Illinois, to take charge of the office there.

W. F. BOWMAN has resigned as chief geologist for the Tide Water Associated Oil Company, at Houston, Texas, to enter private practice as consulting geologist.

H. W. C. PROMMEL, consulting geologist of Denver, Colorado, is author of a paper, "Pennsylvanian Basin of West Central Colorado Geologized," in the September 23 issue of the *Oil and Gas Journal*.

T. F. JOHNSTON recently resigned as party chief of a seismograph crew for The Texas Company, to take graduate work at the University of Texas.

NORVAL NICHOLS has accepted a position with the Humble Oil and Refining Company at Odessa, Texas.

WILLIAM L. RUSSELL, formerly at Houston, Texas, has moved to Harrisburg, Illinois, and may be addressed at the Pickford Apartments, 112 West Poplar Street.

ROBERT G. HAMILTON has been transferred from Wharton, Texas, to the Oklahoma City office of the Schlumberger Well Surveying Corporation.

CLARENCE L. LEE has changed his address from Wahoo, Nebraska, to Casa Blanca Apartments, Santa Maria, California.

At the fifth annual Illinois Mineral Industries Conference held at Urbana-Champaign, October 8 and 9, the following papers were scheduled in

the group on current developments in oil and gas: "Developments in Illinois since January 1, 1937," by ALFRED H. BELL; "Oil Exploration in the Eastern Portion of the Illinois Basin," by THERON WASSON; "Water-Flooding," by PAUL D. TORREY; and "Recent Developments in Water-Flooding in Illinois Oil Fields," by FREDERICK SQUIRES.

An advisory committee on the American Petroleum Institute's research project No. 27, "Function of Water in the Production of Oil from Reservoirs," has been appointed with the following members: E. G. GAYLORD, chairman, Standard Oil Company of California, San Francisco; K. C. HEALD, Gulf Oil Corporation, Pittsburgh; C. V. MILLIKEN, Amerada Petroleum Corporation, Tulsa; T. V. MOORE, Humble Oil and Refining Company, Houston; K. B. NOWELS, Forest Development Corporation, Abilene, Texas; R. B. ROARK, Shell Petroleum Corporation, Tulsa; A. C. RUBEL, Union Oil Company of California, Los Angeles; W. C. SHUTTS, Standard Oil Development Company, New York City; and F. E. WOOD, Standard Oil Company of Indiana, Chicago. F. E. BARTELL, of the department of chemistry, University of Michigan, will be in charge of the work and will soon make a survey of the Bradford oil field. He will be aided by FRANK C. BENNER and WESLEY W. RICHES, research assistants.

The S.S. *Wallace E. Pratt* was launched, October 2, at Chester, Pennsylvania, by the Sun Shipbuilding and Dry Dock Company for the Standard Oil Company of New Jersey. Miss Nancy Jane Pratt was sponsor.

C. F. BOWEN, chief geologist of the Standard Oil Company of New Jersey, New York, has returned from an extended journey in the Orient.

HAROLD LEE CROCKETT has joined the geological department of the Ohio Oil Company at Wichita, Kansas.

C. D. ROBINSON, of the Arkansas Fuel Oil Company, is in charge of the McAllen, Texas, office, assisted by J. P. JONES.

HARRY F. WRIGHT, consulting geologist and engineer, Tulsa, Oklahoma, has an article, "Seismic Disturbances Induced by Deep Rotary Drilling," in the *Oil and Gas Journal* of September 30.

H. C. GEORGE, head of the Petroleum Engineering School at the University of Pittsburgh, died last month, at the age of 56 years.

SAMUEL SCHULITS talked on "Problems Relating to the Transportation of Silt by Streams," at the regular meeting of the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, October 4.

C. W. TOMLINSON, of Ardmore, Oklahoma, spoke before the Tulsa Geological Society, October 4, on the subject "The Big-Horn-Yellowstone Structural Field Conference."

LLOYD I. YEAGER, of the Cities Service Oil Company, has been transferred from the office of district geologist at Wichita, Kansas, to be assistant geologist at Roswell, New Mexico.

VINCENT W. VANDIVER, formerly with the Standard Oil Conpany of New Jersey, is in the land and geological department of the Wilshire Oil Company, 2455 East 27th Street, Vernon, California.

HOWARD L. TIPSWORD, formerly with the Amerada Petroleum Corporation at Tulsa, Oklahoma, has a year's leave to work toward an A.M. degree in paleontology at Indiana University.

R. O. RHOADES has changed his address from the Kuwait Oil Company, Persian Gulf, to Gulf Exploration Company (Great Britain) Ltd., 3 London Wall Buildings, London E.C. 2, England.

ERNEST GUY ROBINSON has moved from Los Angeles, to the St. Louis office of the Shell Petroleum Corporation.

R. M. KLEINPELL has resigned as assistant geologist in the field service of the United States Geological Survey.

J. B. WHISENANT of Whisenant and Trenchard, geologists, San Antonio, Texas, has moved to Illinois and has opened an office for his firm at 1403 Charleston Avenue, P.O. Box 55, Mattoon, Illinois.

ARTHUR C. MUNYAN has joined the Geological Survey of Georgia (Department of Natural Resources), 425 State Capitol, Atlanta, Georgia.

PERRY OLCOTT, geologist for the Humble Oil and Refining Company, talked on "Cost of Acquisition of Crude Oil Reserves," before the Houston Geological Society, September 23.

L. S. CORYELL is with the Indian Territory Illuminating Oil Company at Abilene, Texas.

GEORGE S. HUME, of the Canadian Geological Survey, Ottawa, talked on "The Oil Situation in Southern Alberta," before the Calgary branch of the Engineering Institute of Canada, the latter part of September.

JOHN WHITNEY LEWIS has been doing consulting work for the Seaboard Oil Corporation, the Atlantic Refining Company, and the Royal Dutch Shell of Cuba, in the Dominican Republic.

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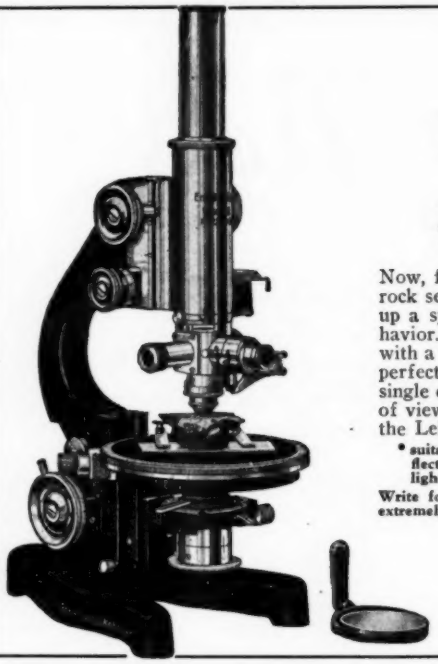

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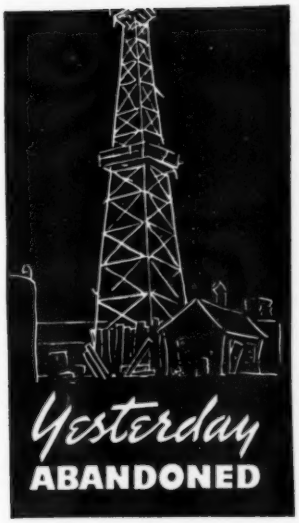

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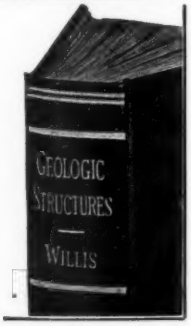

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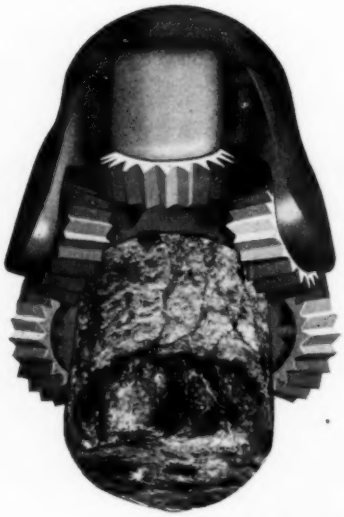

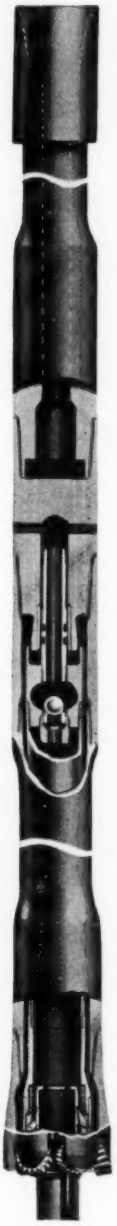

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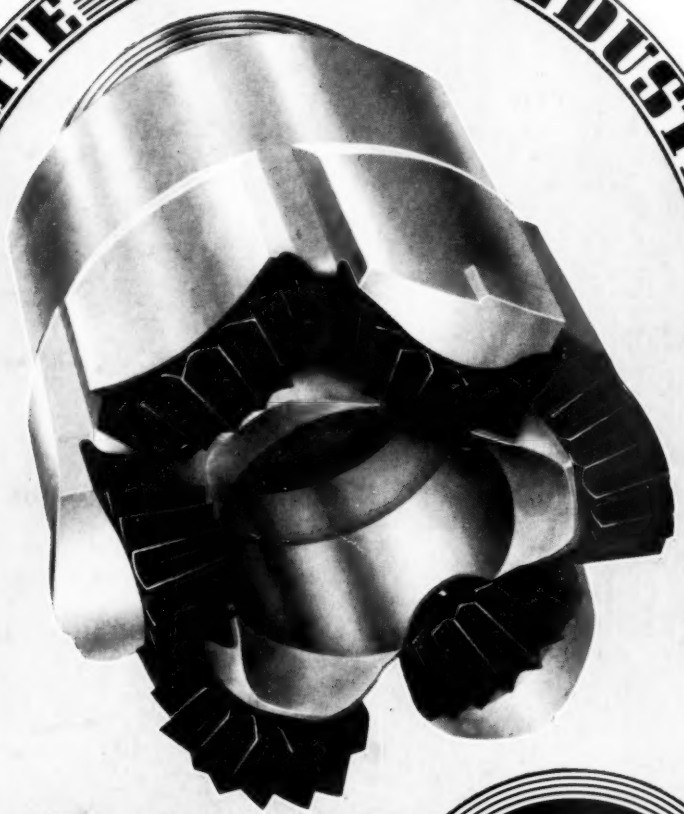

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